Report on Introducing Competition in European Air Traffic Control Provision using Game Theoretic Principles

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COMPAIR

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COMPAIR

COMPETITION FOR AIR TRAFFIC MANAGMENT

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Abstract

In this deliverable we focus on whether it is possible to introduce competition *for* the market in air traffic control in Europe and the likely outcomes. We develop a two-stage, network, congestion game in which multiple air navigation service providers bid to serve Member State airspace. Airlines subsequently choose their optimal flight paths such that they minimize their operating costs. The individual Member States set up an auction in which they specify minimum service levels and the rules of the auction, such as the right to increase charges as a function of air service levels. The winners of the auctions are the service providers that bid the lowest charge. We test the likely equilibria outcome if the companies are for-profit or non-profit air navigation service providers. The results suggest that introducing competition for the market via outsourcing service provision may reduce charges by up to half the current levels. It would also appear that auctioning the service is likely to lead to defragmentation of the European system as companies win more than one auction. Finally, it would appear that for-profit companies are highly likely to invest in SESAR technologies thus encouraging technology adoption faster than appears to be occurring today. We note that it is important to ensure a sufficient number of competitors for the auction process to be successful over time. Without an auction process, non-profit companies would be strictly preferable to both the current state agency and to a government corporation.

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Executive Summary

Context

ACCHANGE[1], one of the SESAR WP-E research projects, included the development of a network congestion game to test a series of scenarios in order to analyse potential paths for change in air traffic management in Europe. The results suggested that horizontal integration across air navigation control providers, known as functional airspace blocks, would appear to be problematic with respect to incentives hence regional forerunners in a bottom-up institutional process would appear to be a preferable approach. Vertical integration between companies may succeed in accelerating change as long as the air traffic control companies are permitted to charge for improved quality, such as reduced congestion. Institutionally, a clear separation of the ATC providers from the Member States and subsequent franchising of the support services and ATC services could further encourage efficiency, consolidation and technology adoption. In this current project, COMPAIR, we take the ideas further in an attempt to understand whether competition for the market could promote the aims of the Single European Skies initiative. The overall goal of the COMPAIR project is to investigate how to introduce competitive incentives in the ATM sector so as to best contribute to the achievement of the European high-level policy objectives for aviation. According to this goal, one of the objectives of the project is the development of quantitative models that enable the evaluation of different ATM market designs.

Objectives and Methodology

In this deliverable, we focus on whether it is possible to introduce competition for the market in air traffic control in Europe and the potential likely outcomes. We develop a two-stage, network congestion game in which multiple air navigation service providers bid to serve Member State airspace. Airlines subsequently choose their optimal flight paths such that they minimize their operating costs. The individual Member States set up an auction in which they specify minimum service levels and the rules of the game, such as the right to increase charges as a function of air service levels. The winners of the auctions are the service providers that bid the lowest peak charge. If more than one bid offers the same peak charge, the winner will be the company setting the lowest off-peak charge. If more than one company offers the same set of charges, the one with local headquarters will win due to national interest concerns. The final rule, should all others remain

[1] http://tmleuven.be/project/acchange/home.htm

equal, will be based on the company that offers the highest levels of capacity. We test the likely equilibria outcome if the companies are for-profit or non-profit air navigation service providers over multiple demand scenarios.

Findings

In the base-run, in which we attempt to replicate the current market, we find that there is no interest in investing in SESAR technologies. If the regulator could enforce much lower charges in the current state via price caps, we find that the ANSPs will simply fail to survive financially. Simply privatizing ANSPs to for-profit firms, without introducing competition through an auction, does not produce change with respect to defragmentation or technology adoption neither does it remove the need for price caps.

The results suggest that introducing competition for the market via outsourcing service provision may reduce charges by up to half the current levels. It would also appear that auctioning the service is likely to defragment the European air traffic control system as companies win more than one auction in neighboring countries. Finally, it would appear that for-profit companies are highly likely to invest in SESAR technologies thus encouraging technology adoption faster than appears to be occurring today.

The transport equilibria outcome appears to be closer to achieving the Single European Skies initiative under for-profit company competition than non-profit. In the case of non-profits, the charges decrease below the current price cap but to a lesser extent than the for-profit case. Moreover, it is less likely that all ANSPs will adopt the SESAR technologies as the current results suggest that only the larger ANSPs will choose to invest. However, without auctions, the non-profit result is superior to that of for-profits or the current system.

In summation, the numerical results show that the introduction of auctions with for-profit ANSPs, assuming the government of the Member State stipulates minimum capacity levels will likely help to achieve the major policy preferences of the European Union; namely lower costs through technology adoption, cost control and defragmentation of the Single European Skies. Furthermore, under this scenario it may be possible to reduce or remove economic regulation as competition is a sufficiently strong force to keep prices reasonable. In all cases, competition is the main driver of change and that a continuation of the current regulation scheme does not produce the well defined Single European Skies objectives.

Abbreviations

Acronym	Definition
ACC	Area Control Centre
ACCHANGE	Accelerating change of air traffic management by regional forerunners
ACE	ATM Cost-Effectiveness
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATFM	Air Traffic Flow Management
CASK	Cost per available seat-kilometre
CNS	Communications, Navigation, Surveillance
COMPAIR	Competition for air traffic management
CRCO	Central Route Charges Office
DFS	Deutsche Flugsicherung; The German ANSP
DSNA	direction des Services de la navigation aérienne; The French ANSP
EC	European Commission Regulation
ENAIRE	The Spanish ANSP
FAA	Federal Aviation Agency
FAB	Functional Airspace Blocks
IFR	Instrument flight rules
JU	Joint Undertaking
LVNL	Luchtverkeersleiding Nederland; The Dutch ANSP
MUAC	Maastricht Upper Area Control Centre
NATS	National Air Traffic Services The UK ANSP
OD	Origin-Destination
PRB	Performance Review Board
SES	Single European Sky
SESAR	Single European Sky ATM Research

Mathematical notation

Notation	Definition
$\boldsymbol{P}$	finite set of origin/destination nodes with indices o, d
$\boldsymbol{T}$	finite set of transit nodes
$\boldsymbol{N}$	set of all nodes, $N = P \cup T$, with indices i, j
$\boldsymbol{B^E}$	set of en-route airspaces
$\boldsymbol{B^P}$	set of terminal tower controls
$\boldsymbol{B}$	set of all airspaces, $B = B^E \cup B^P$, with index b
$\boldsymbol{A_b}$	set of arcs in airspace *b*, with index $a = (i, j)$
$\boldsymbol{A}$	set of all arcs A = $\bigcup_{b \in B} A_b$
ϑ_a	kilometres of service on arc a
$\boldsymbol{d_s}$	surface square kilometre of airspace s
$\boldsymbol{W} = \{\boldsymbol{1}, \boldsymbol{2}\}$	set of peak (1) and off-peak (2) time windows, with index w
$\boldsymbol{L}$	finite set of airlines, with index l
$\boldsymbol{S}$	finite set of ANSPs, with index s
$\boldsymbol{h_{sb}} = \{\boldsymbol{0}, \boldsymbol{1}\}$	1 if *b* is the home area of en-route ANSP s; 0 otherwise (home bias)
$\boldsymbol{D_{lod}}$	demand of airline l for service from origin o to destination d
$\boldsymbol{C_l^O}$	airline l's variable operating cost per unit
$\boldsymbol{C_{lw}^R}$	airline l's reduced revenue from off-peak service for $w = 2$
$\boldsymbol{C_{lbw}^G}$	airline l's congestion cost per unit in airspace *b* per time window *w*
$\boldsymbol{C_{od}^Q}$	airline outside option cost to service from origin o to destination *d*
$\boldsymbol{C_s^{S\lambda}}$	ANSP s's labour cost per unit
$\boldsymbol{C_s^{St}}$	ANSP s's cost of technology per unit
$\boldsymbol{\gamma_s}$	fraction of capacity used effectively such that congestion does not reach gridlock (e.g. 0.8)
$\boldsymbol{\alpha}, \boldsymbol{\beta}, \gamma, \boldsymbol{\zeta}$	Parameters in Cobb-Douglas production function
$\boldsymbol{\eta}$	airline operating cost saving from adoption technology adoption
$\boldsymbol{\varsigma}$	airline congestion cost saving from adoption of new technologies
τ_{sb}^0	ANSP s's price cap per unit in airspace *b*
$\boldsymbol{k_b^0}$	current capacity provided in airspace *b*
$\boldsymbol{\xi}$	constant balancing capacity and profits
$\boldsymbol{\upsilon^E}$	maximum number of auctions in which ANSP is permitted to participate
$\boldsymbol{f_{bw}^0}$	minimum level of service i.e. number of flights to be served with minimal delay in airspace *b* in time window *w*
$\boldsymbol{\varphi_{bw}^+}, \boldsymbol{\varphi_{bw}^-}$	fraction increase (or decrease) in charge permitted for providing output above (or below) the minimum service level requirement in airspace *b* in time window *w*
$\boldsymbol{X_{sb}} = \{\boldsymbol{0}, \boldsymbol{1}\}$	1 if ANSP s wins the auction to serve airspace b ; 0 otherwise
τ_{sbw}	ANSP s's charge per unit in airspace b during time window w
$\boldsymbol{\lambda_s}$	level of labour employed by ANSP s
$\boldsymbol{t_s}$	level of technology purchased by ANSP s
$\boldsymbol{k_s}$	level of capacity set by ANSP s
$\boldsymbol{K_s^e}$	effective capacity after auction winner s announced
$\boldsymbol{Y_b}$	operator selected to serve airspace b

f_{lodaw}	airline l's flow on arc a serving origin-destination pair (o, d) during time window w
f^{Q}_{lod}	airline l's non-flow from origin o to destination d

1 Introduction

The COMPAIR project (http://compair-project.eu/) discusses potential options for introducing a variety of forms of competition into the air traffic control system. Competition can be introduced at various levels and in different ways. The current approach is more focused on centrally steered regulation. COMPAIR focusses on the introduction of competition as a trigger for change. At the start of the project we identified different concepts to be further analysed. These concepts were first evaluated qualitatively and using small economic models. Within this work we focus on analysing quantitatively the potential of two institutional designs: governance and tendering for en route ATM.

Currently, the organizational form of air traffic control provision in Europe is based on state bodies and government corporations, with the exceptions of NATS (United Kingdom), Skyguide (Switzerland) and Maastrict Upper Airspace known as MUAC. NATS, a public-private partnership was created in 2000[2] with the British government owning 49% of the shares and with a board composed today of stakeholders and a private pension fund. Skyguide is a non-profit, joint stock company with the Swiss government holding 99% of the shares, but legally able to reduce this to 51%, and with a board consisting of seven appointed members (Elias, 2015 [15]). MUAC began in the 1960s as an international, non-profit organization operated by Eurocontrol that serves the upper airspace of four countries: Belgium, the Netherlands, Luxembourg and North-West Germany. However, for the most part, state agencies and government corporations have developed within continental Europe with varying degrees of commercialization, which impact access to private financial markets (Button and McDougall, 2006 [10]; Cook, 2007 [13]; McDougall and Roberts, 2008 [27]). All the air navigation service providers (ANSPs) are currently price capped by the Performance Review Board (PRB) acting as a regulator at the European level. The PRB undertakes five year assessments as to the level of the price cap, with the third assessment process expected to begin in 2020. Air traffic control charges contribute 6 to 12% to the cost of a ticket according to the European Commission (2013)[17]. In a

[2] http://www.nats.aero/about-us/our-history/. Accessed on 31/5/2017.

previous WP-E funded project, ACCHANGE, it is argued that the economic regulators are relatively weak as compared to the labour unions such that the system is relatively inefficient from a cost perspective (Blondiau et al., 2016)[8].

Given the current system, it has been argued that economies of scale are missed due to the fragmentation of the system because each Member State is served by a single provider with geographical monopoly status (Button and Neiva, 2013[11]; Adler et al., 2014[1]). For this reason, the European Union created nine providers in 2004, known as Functional Airspace Blocks (FABs), by aggregating the current ANSPs across states[3]. The potential need for defragmentation can be seen from a comparison of the European air traffic control system to its American counterpart, the Federal Aviation Agency (FAA), which serves the entire United States with 22 air route traffic control centres. In 2014, the FAA provided a comparable quality of service at a 35% lower unit cost compared to that of the European system. This gap continues to exist despite a considerable decrease since 2006 when it was estimated to be approximately 46%. The closing of the gap is due to both a reduction of 5.3% in unit costs in the European system and an increase of 14.1% in the United States unit costs (Eurocontrol, 2016b[20]). It should also be noted that literature from the 1990s have clearly argued that the FAA is neither efficient nor well managed (Kettl and Dilulio, 1997[25]; Treanor, 1997[40]).

In addition to these issues, there has been an on-going effort to increase the use of technology in air traffic control production in both the US and Europe. In 1999, around one third of flights were delayed for more than fifteen minutes in the Eurocontrol area (Raffarin, 2004[31]). Delays began increasing again in 2005. By 2008, the European en-route average delay was 90% higher than the agreed targets (Eurocontrol, 2008[16]). This substantial congestion led to the belief that new technologies were needed in order to further increase capacity. This in turn led to the creation of the public-private partnership known as the SESAR Joint Undertaking. SESAR JU has been investing in the development of such technologies, some of which are in the process of being implemented today. However, progress on the creation of FABs and employment of technologies has been slower than expected (Baumgartner and Finger, 2014[6]).

[3] https://www.eurocontrol.int/dossiers/fabs. Accessed on 9/9/2017.

In this research we intend to understand whether a change in ownership form may help to simultaneously:

- resolve the issue of fragmentation;
- encourage the faster adoption of new technologies.

We assume that companies will bid for more than one airspace and should be able to reduce cost inefficiencies accordingly. An additional windfall may also be to reduce or remove the need for economic regulation, were competitive markets to be developed despite the geographical monopoly required to ensure safe air traffic control provision across the European skies.

A process of privatization may need to take place in order to enable outsourcing of this activity. Vickers and Yarrow (1991)[42] identify three types of privatization: privatization of a competitive product market free from substantial market failures; privatization of monopolies where the government usually continues to maintain some form of regulation; and privatization in the form of contracting out a former publicly financed service. With respect to the latter form, privatization raises the perennial question with regard to safety standards. Consequently, it will be important for the current agencies to remain in charge of ensuring safety levels (Kettl and DiIulio, 1995[25]; Sclar, 2003[37]). Clearly, the National Supervisory Authorities and European Aviation Safety Agency would continue to monitor and set safety standards. Furthermore, it needs to be recognized that a change in ownership form could result in pressure to lower capacity levels, potentially leading to longer delays and congestion in the skies (Sappington and Stiglitz, 1987[36]). Each country would need to set minimum standards when creating contracts with public or private companies. In summation, although economic regulation may no longer be necessary, safety and quality / capacity monitoring will likely need to continue.

Sappington and Stiglitz (1987) [36] specify three objectives for governments when choosing between private and public production; economic efficiency, equity and rent extraction. These objectives may be achieved through privatization if "the ideal settings" for privatization exist. These ideal settings require there to be two or more bidders in the auction for the right to provide the good and that the firms are risk-neutral with symmetric beliefs about the least-cost production technology. The real cost of production is only revealed after winning the bid but prior to production. The government must also have a certain valuation of the level of output required. Whilst most of these settings probably do exist in the air traffic control market in Europe, the governments of the Member States will bear the contracting costs and implementation issues may still arise, requiring the need to measure performance on an on-going basis. Blank (2000)[7] argues that the more the quality of service is measurable and observable, the more it is possible for the government to act only as a regulator rather than an operator.

Private (and public) enterprise could be in the form of for-profit or non-profit organizations. Goulet and Frank (2002)[23] found that employees of for-profit organizations have a higher commitment than those in non-profit organizations, although the employees with the least commitment are those in the public sector. Another model of ownership is a government corporation which is considered to be a modest form of privatization where the government does not completely withdraw rather retains some control of the firm as exists today, for example in Germany. Corporatization however can face softer budget constraints which diminish incentives to minimize production costs as the government might tolerate losses and continue to finance the firm (Armstrong and Sappington, 2006[4]).

Note that private does not equal for-profit and public does not equal non-profit. While a public non-profit organization receives the majority of its funding from the general public, a private non-profit organization receives most of its funds from only a few private sources, such as through donations from a single family/company, investment income or the customers served. A non-profit organization is a company created for purposes other than earning a profit. Typical non-profit organizations include hospitals, schools, churches, political organizations, public clinics, labour unions, research institutes, etc. ANSPs can take either form, as illustrated in Figure 1.

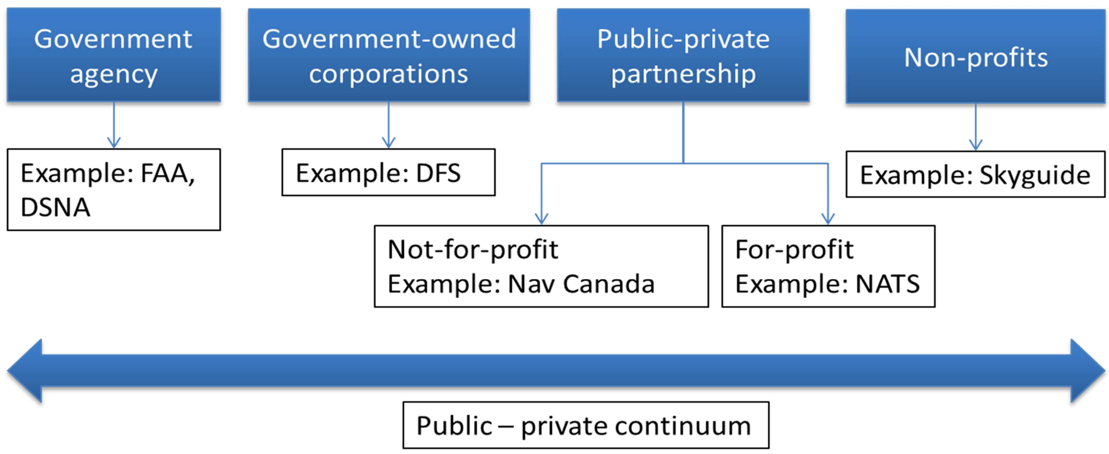

Figure 1: Private-Public continuum of ANSPs

In summation, it is unclear whether each airspace will be better served by a public corporation, private regulated monopoly or by contracting out the service to a for-profit or non-profit company. Consequently, we develop a game theoretic model in order to estimate the potential equilibria outcome of any change in ownership form. Within this modelling framework, we will test the potential impact of creating an auction system with for-profit or non-profit entities serving markets for a limited timeframe of five to ten years, after which each country would then hold another auction. This type of competition, for the market rather than in the market, may create the incentives necessary to achieve the aims of the Single European Skies initiative. In this deliverable, we first discuss the modelling approach developed for the analysis. In Section III, we present a case study covering six countries in Western Europe, which together serve approximately 50% of the air traffic control movements in Europe on an annual basis. In Section IV, we present the transport equilibria outcomes of the various scenarios tested and in Section V we draw conclusions and suggest potential future directions.

2 Modelling approach

We develop a two-stage, congested network, Nash equilibria game with multiple actors in each stage in order to answer the question: what would be the likely outcomes were Member States to contract out their air traffic control provision. In this section, we first present notation and assumptions prior to defining the models for each of the sets of players in the game. Stage zero defines the decisions of the Member State regulator, which are set exogenously prior to analysing the game, hence defines a specific scenario. The first stage of the game describes the air traffic control service providers who set their charges and capacities. In stage two, the airline operators choose their flight paths given the first stage decisions of the ANSPs.

The network underlying the congestion game is composed of a set of origin, transit and destination nodes, and a set of arcs representing services offered. We use the following network definitions:

P	finite set of origin/destination nodes with indices o, d
T	finite set of transit nodes
N	set of all nodes, $N = P \cup T$, with indices i, j
B^E	set of en-route airspaces
B^P	set of terminal tower controls
B	set of all airspaces, $B = B^E \cup B^P$, with index b
A_b	set of arcs in airspace b, with index $a = (i, j)$
A	set of all arcs A = $\cup_{b \in B} A_b$
ϑ_a	kilometres of service on arc a
d_s	surface square kilometre of airspace s
$W = \{1,2\}$	set of peak (1) and off-peak (2) time windows, with index w

for the ANSPs and airlines we use the following definitions:

L	finite set of airlines, with index l
S	finite set of ANSPs, with index s
h_{sb}	= *1* if *b* is the home area of en-route ANSP *s*; 0 otherwise (home bias)
D_{lod}	demand of airline l for service from origin o to destination d

and we use the following definitions for costs and charges:

C_l^O	airline l's variable operating cost per unit
C_{lw}^R	airline l's reduced revenue from off-peak service for $w = 2$
C_{lbw}^G	airline l's congestion cost per unit in airspace *b* per time window *w*
C_{od}^Q	airline outside option cost to service from origin o to destination *d*
$C_s^{S\lambda}$	ANSP s's labour cost per unit
C_s^{St}	ANSP s's cost of technology per unit
γ_s	fraction of capacity used effectively such that congestion does not reach gridlock (e.g. 0.8)
α, β,γ, ζ	parameters in Cobb-Douglas production function
η	airline operating cost saving from adoption technology adoption
ς	airline congestion cost saving from adoption of new technologies
τ_{sb}^0	ANSP s's price cap per unit in airspace *b*
k_b^0	current capacity provided in airspace *b*
ξ	constant balancing capacity and profits

We assume that in an initial underlying stage, the government sets the scene and minimum level of service for the bidding process if relevant. These are not decision variables of the game, rather are chosen prior to running the specific scenario. Service levels could be defined by an average delay or alternatively by a delay distribution, such as the percentage of flights delayed more than fifteen minutes. Notation includes the following:

υ^E	maximum number of auctions in which ANSP is permitted to participate
f_{bw}^0	minimum level of service i.e. number of flights to be served with minimal delay in airspace *b* in time window *w*
$\varphi_{bw}^+, \varphi_{bw}^-$	fraction increase (or decrease) in charge permitted for providing output above (or below) the minimum service level requirement in airspace *b* in time window *w*

1st stage ANSP decision variables:

X_{sb}	=1 if ANSP s wins the auction to serve airspace b ; 0 otherwise
τ_{sbw}	ANSP s's charge per unit in airspace b during time window w
λ_s	level of labour employed by ANSP *s*
t_s	level of technology purchased by ANSP *s*

the set of auxiliary variables include:

k_s	level of capacity set by ANSP s
K_s^e	effective capacity after auction winner s announced
Y_b	operator selected to serve airspace *b*

2nd stage airline decision variables:

f_{lodaw}	airline l's flow on arc a serving origin-destination pair (o, d) during time window w
f_{lod}^Q	airline l's non-flow from origin o to destination d

We assume that within each auction, the bidders are symmetric, risk-neutral, bid independently and have access to complete information. In order to ensure that the European Union is not served by a single provider which would create a monopoly, we assume that no company is permitted to participate in more than a maximum number of auctions. Alternatively, the ANSPs could be limited to serving a maximum share of the European market. In the case study presented in Section III, in which we model six auctions, we assume that the ANSPs must serve a contiguous airspace hence may only bid in their home country and any other country with a common border. Since the airspace modelled represents 50% of the European market, we assume that the ANSPs will be limited to a maximum of two bids which in turn caps the market share to 30% of the total European airspace. We note that it is possible for an ANSP to serve non-contiguous airspaces but (1) the level of productive efficiency gains is less clear in this case and (2) it is a helpful assumption for computational purposes because it reduces the potential set of combinations of auctions in which the individual ANSP can bid.

In the bid process, the ANSP will set a peak and off-peak price and specify a level of service in each auction. If the provider offers a service level higher than the minimum, the charge per km increases (as occurs today in the UK which is referred to in the NATS annual report[4]) up to 20% for example. If two or more companies bid the lowest peak price, the winner will be chosen based on the off-peak price bid, followed by home bias and finally the service level offered. If all four values are the same then the winner is chosen arbitrarily among the bidders. Home bias refers to the fact that each company has a headquarters which determines their home country and any country would prefer home production, thus representing national interests.

We model the ANSPs as labour rent maximisers, private company profit maximisers or not-for-profit capacity maximisers. Consequently, we assume that government organizations behave as labour rent maximisers, since labour unions appear to be relatively powerful due to their ability to prevent all flights should they strike. Furthermore, based on an assessment of wages in this sector compared to people employed in similarly technical employment, it would appear that this assumption is the most reasonable (Blondiau et al. 2017). Whilst private companies are clearly profit maximsers by definition, the objective function of non-profits, such as Nav Canada, are less clear. We assume that these organisations are interested in providing a quality service, which we model as capacity maximisation, whilst also earning no profits. Under each scenario, the service provider best responds to the choices of its competitors, taking as given the equilibrium service flows f^{*}_{lodaw} that will be chosen by the airline operators in the second stage of the game, thus leading to a sub-game perfect Nash equilibrium. The equilibria outcome indicates that no player in either of the stages would find it worthwhile to deviate from their current choices, given the choice of all other actors in the market. The airline operators create flows after taking into account the air traffic control charges in each airspace and the levels of congestion, in part caused by the capacity levels chosen by the ANSPs.

[4] https://www.nats.aero/wp-content/uploads/2017/07/NATS6247_AnnualReport_2017-FULL.pdf accessed on 9/12/17

2.1 Scenario 1 (ANSPs as labour rent maximisers):

Scenario 1, the base-run scenario, defines a labour rent maximiser ANSP which likely represents the objective of the current state agency or government corporation, as was shown in Blondiau et al. (2016 and 2017).

$$Max\ \lambda_s \tag{1.1}$$

subject to

$$\zeta(\lambda_s)^{\alpha}(t_s)^{\beta} = k_s \tag{1.2}$$

$$\sum\nolimits_{b\in B^E} h_{sb}\left(\sum\nolimits_{w} \tau_{sbw} F^{*}_{bw}\right) - C^{Sl}_{s}\lambda_s - C^{St}_{s} t_s = 0 \tag{1.3}$$

$$0 \leq \tau_{sb2} \leq \tau_{sb1} \leq \tau^{0}_{sb}\ \ \forall\, s, b \tag{1.4}$$

$$\lambda_s \geq \lambda', t'' \geq\ t_s \geq t'\ \ \forall\ s \tag{1.5}$$

whereby:

$$\sum\nolimits_{a\in A_b}\left\{\vartheta_a \sum\nolimits_{l}\sum\nolimits_{od} f^{*}_{lodaw}\right\} = F^{*}_{bw}\ \ \forall\ b \in B^E, w \tag{1.6}$$

The objective function **(1.1)** maximises labour subject to the production function **(1.2)**. The production function is estimated based on levels of labour and technology. Current levels of technology are represented by *t*=1 and any adoption of SESAR technologies will increase this value such that complete adoption of SESAR step 1 will set *t*=2. Consequently, this is a decision variable of the ANSP in the model. Constraint **(1.3)** requires the ANSPs to arrive at zero profits. However, given that the ANSPs today earn small profits, we also check the values for parameters different from zero. Constraints **(1.4)** set price caps on the charges where relevant and ensures that peak prices are greater than or equal to off-peak price bids. Constraints **(1.5)** set lower bounds on labour levels of at least 100 air traffic controllers (Eurocontrol, 2016a[19]) and lower and upper bounds on technology ($1 \leq t \leq 2$). In equations **(1.6)**, the optimal, equilibria flows are defined given the charges and capacity levels set in the first stage.

2.2 Scenario 2 (ANSP as private, profit maximising companies):

We define a profit maximisation objective function per service provider *s*. The costs include labour and investment in technology. The revenues draw from the peak and off-peak charges multiplied by equilibria airline flows plus additional revenues from achieving higher than expected service levels less penalties paid for poor service level standards below those pre-set by the government in stage 0. Model **(2)** includes a set of constraints in which the charges are price capped, to be included where relevant.

$$Max - C_s^{Sl}\lambda_s - C_s^{St}t_s \tag{2.1}$$
$$+\sum_{b\in B^E}\begin{cases}\sum_w \tau_{sbw}\left(F_{bw}^* + max\{0,\varphi_{bw}^+\left(F_{bw}^* - f_{bw}^0\right)\} - max\{0,\varphi_{bw}^-\left(f_{bw}^0 - F_{bw}^*\right)\}\right) & if\ Y_b \\ 0 & otherwise\end{cases}$$

subject to

$$\sum_{b\in B^E} X_{sb} \leq \upsilon^E \quad \forall\, s \tag{2.2}$$

$$\zeta(\lambda_s)^\alpha (t_s)^\beta \left(\sum_{b|Y_b=\{s\}} d_b\right)^\gamma = K_s^e \tag{2.3}$$

$$0 \leq \tau_{sb2} \leq \tau_{sb1} \leq \tau_{sb}^0 \quad \forall\, s, b \tag{2.4}$$

$$\lambda_s \geq \lambda', t'' \geq\ t_s \geq t' \quad \forall\, s \tag{2.5}$$

whereby:

$$Y_b\ = \arg\,\text{leximax}_{s'|X_{s'b}=1}\{-\tau_{s'b1}, -\tau_{s'b2}, h_{s'b}, k_{s'}\} \tag{2.6}$$

$$\sum_{a\in A_b}\left\{\vartheta_a \sum_l \sum_{od} f_{lodaw}^*\right\} = F_{bw}^* \quad \forall\, b \in B^E, w \tag{2.7}$$

$$k_s\left(\frac{\sum_{b|Y_b=\{s\}} k_b^0}{\sum_{b|X_{sb}=1} k_b^0}\right) = K_s^e \tag{2.8}$$

The objective function **(2.1)** maximises revenues less costs of labour and technology. Revenues may increase if the ANSP exceeds the pre-set minimum level of service and is penalised if service is below the pre-set government demand as set out in the auction. Constraints **(2.2)** limit the maximum number of bids in which a company may participate. Constraint **(2.3)** defines capacity levels as a function of labour, levels of technology employed and size of airspace, which in turn is a function of the number of tenders in which the company participates. Constraints **(2.4)** cap the charges if relevant and (2.5) set lower bounds on labour levels and lower and upper bounds on technology. Equation (2.6) defines the winner of the auction based on the lexicographic rules described previously (peak price, lowest off-peak price, home bias and finally capacity levels offered). Equations (2.7) define the optimal flows as a function of the second stage, airline choices in equilibria. Finally equation (2.8) defines the effective capacity of ANSP s given the choice of winner in the auction. If an ANSP wins all airspaces in which they bid, the effective capacity level will equal k_s, however if they fail to win one of their bids, their capacity levels will be reduced accordingly. If they fail to win any bids, their capacity levels drop to zero and we assume that they leave the market.

2.3 Scenario 3 (ANSPs as non-profit companies):

Scenario 3 defines a non-profit ANSP maximising capacity and minimising profits with parameter ξ acting as a balance between the two objectives. Since the first element in the objective function is in terms of annual flight-km that may be served and the second element is in terms of monetary profits, it is necessary to set the parameter such that both objectives are considered approximately equally. Currently, we assume that the ANSPs will aim for approximately zero profits in order to meet their mandate.

$$Max\ K_s^e - \xi \left| \sum_{b \in B^E} \sum_w \left(\tau_{sbw} F_{bw}^* - C_s^{Sl} \lambda_s - C_s^{St} t_s \right) \right| \tag{3.1}$$

subject to

equations (2.2) to (2.8)

2.4 Airlines

We assume that multiple airlines are being served in this market and each airline operator, given their network type and schedule, attempt to minimise their costs. The airline cost functions, which are modelled in the second stage of the game, are composed of five categories, all of which are impacted to some degree by the service providers. This objective function, equation (4.1), includes operating costs C_{la}^O , cost C_{law}^R from flying off-peak (equivalent to the loss of revenues due to lower airfares charged in the off-peak), a congestion cost C_{ls}^G, ANSP charges τ_{lsw} and a cost for not flying, C_{od}^Q. In order to account for elastic demand, there exists an outside option flow, f_{lod}^Q, which represents the choice to reduce service, with cost C_{od}^{Q} per flow unit, which will be preferred if the total costs of being served are too high. Furthermore, the operating costs and congestion costs are impacted by the effective capacity provided by the winning ANSP which in turn is dependent on the level of technologies employed. In other words, we assume lower airline operating costs (η) and congestion costs (ς) if SESAR Step 1 technologies are employed, as outlined in substantial detail in the 2012 ATM Master Plan. The level of technologies employed is determined by the winning ANSP in the first stage.

$$\Psi_l \equiv \sum_w \sum_{b\in B^E} \sum_{a\in A_b} \left[C_{la}^{O} \left(1 - \max\left\{\eta \left(\frac{K_{Y_b}^{e}}{k_b^{0}} - 1\right), 0\right\}\right) + C_{law}^{R} + C_{lbw}^{G} \left(1 - \max\left\{\varsigma \left(\frac{K_{Y_b}^{e}}{k_b^{0}} - 1\right), 0\right\}\right) \left(\sum_{l'od} f_{l'odaw}\right) + \tau_{sbw} \right] \vartheta_a \sum_{od} f_{lodaw} + \sum_{od} C_{od}^{Q} f_{lod}^{Q} \tag{4.1}$$

In a user equilibrium outcome, we assume that each airline chooses paths and time windows taking into account only its own costs and taking the flows of the other airlines as given. Specifically, each airline *l* considers only its own congestion costs and ignores the external congestion costs imposed on the other airlines. Since the pioneering work of Pigou (1920), there has been a huge and well established literature analysing the efficiency of congested service systems, including network congestion games. The standard approaches to analyse such settings include Wardrop equilibria (Wardrop 1952[43]) and the potential game approach (Rosenthal 1973[34], Monderer and Shapley 1996[28]), both of which consider atomistic and identical customers who each demand an infinitesimal flow in the face of exogenous congestion cost functions. A different approach assumes that competing customers are non-atomistic and have market power in that each customer controls a non-negligible fraction of the total flow (e.g., Cominetti et al., 2009[12]). The two approaches arrive at the same equilibria outcomes only under specific assumptions (Haurie and Marcotte 1985[24]). The two-stage game of price competition between service providers in the presence of congestion developed here is the first to consider oligopolistic markets in both stages of the game, i.e. allow for non-atomistic, heterogeneous airline operators with market power in the second stage who react to the first stage ANSP charges. Sub-game perfect Nash equilibria[5] allow airline operators to consider

[5] In a multi stage game, we search for the best response of a specific player in the upper level i.e. first stage, and then move to the second level and search for the best responses of all players in the second, lower level and so on. The search then continues with the subsequent player in the upper stage. A cycle is completed when all players in the upper level have been analysed. The game ends with a sub-game perfect equilibrium once an entire cycle is completed in which no player, in either stage of the game, deviates from their current choices

self-imposed congestion across the various routes, potentially leading to interior point flows that do not occur with atomistic Wardrop equilibria. This is critical to the issue of existence of equilibria in the two-stage game when airlines are heterogeneous, hence impact the comparative conclusions we can draw from the analysis.

$$\mathrm{Min}_{f_{lodaw}, f_{lod}^{T}} \Psi_l \tag{4.2}$$

s.t.

$$\sum_w [\sum_{j|(o,j)\in A} f_{lod(o,j)w} - \sum_{j|(j,o)\in A} f_{lod(o,j)w}] + f_{lod}^{Q} = D_{lod}\ ,\ \ \forall l \in L, \forall o, d$$

$$\sum_w [\sum_{j|(j,d)\in A} f_{lod(d,j)w} - \sum_{j|(d,j)\in A} f_{lod(d,j)w}] + f_{lod}^{Q} = D_{lod}\ ,\ \ \forall l \in L, \forall o, d \tag{4.3}$$

$$\sum_{j|(j,i)\in A} f_{lod(j,i)w} - \sum_{j|(i,j)\in A} f_{lod(i,j)w} = 0\ , \forall l \in L, w \in W, o, d, i \in N\ (i \neq o, d)$$

$$\sum_l \sum_{od} \sum_{b|Y_b=\{s\}} \sum_{a\in A_b} \vartheta_a f_{lodaw}^{*} \leq \gamma_s K_s^{e}\ \ \forall\, s \in S, w \in W \tag{4.4}$$

$$f_{lodaw} \geq 0\ , f_{lod}^{H} \geq 0\ ,\ \forall l \in L, o, d \in N, a \in A, w \in W\ . \tag{4.5}$$

Constraints **(4.3)** sum the incoming less the outgoing flows to be equal to the (negative) demand at the (origin) destination and zero when using a transit point. The total flows are reduced by those flights that have been dropped via the outside option. Constraints **(4.4)** ensure that the total flow is less than or equal to the effective capacity set by the wining ANSP in the first stage. Constraints **(4.5)** ensure non-negativity of the flows and non-flow.

2.5 Solving the mathematical programs

For the airline operators, the convex, quadratic objective function with linear constraints is solved using standard CPLEX software and is guaranteed to be solved to optimality due to the Karush Kuhn Tucker conditions (Kuhn, 2014[26]).

(Selten, 1975[38]). A best response sets the values of the decision variables of a specific player such that it achieves an objective e.g. profit maximization or cost minimisation *GIVEN* the choices of all other players in the market.

For the first stage of the game, an equilibrium in mixed price strategies always exists[6]. However, such an outcome would be very difficult to interpret hence we search for pure strategy equilibria outcomes. Although an equilibrium in pure price strategies may fail to exist, we show that it does exist in the network analysed in the next section, provided there are sufficient bids (at least two bidders in each Member State). We note that it is possible that more than one equilibrium outcome is possible in this game but due to time restrictions have not been able to test all possible actor orders. Consequently, the equilibria presented are analysed at a general level rather than describing which player precisely would win such auctions.

In order to solve the game, we develop a customised algorithm based on a local search procedure. Starting with the first potential company, bidding in their home country and one adjacent airspace, we search for an optimal solution in a radius of 50% around the starting solution. The starting solution is the 2014 transport equilibria outcome, as presented in Table 1 of Section III. For the integer variables, namely the airspaces to be considered for bidding, the search procedure tests for all potential combinations of bids per ANSP individually. For a specific combination of bids, the program then solves for all airlines and the search continues until the optimal solution for the ANSP company is found i.e. the algorithm moves between the ANSP under investigation and the second stage, airline strategies. The algorithm then moves to the next potential set of bids for the first ANSP until all such potential bid sets are exhausted. Subsequently, the algorithm moves to the second ANSP being modelled. A complete cycle is concluded once all potential ANSP bid combinations are analysed. The cycles continue at the same radius around the continuously updated solution until no ANSP changes their decision variable values. The radius is then reduced by half and the cycles continue. An equilibria outcome is determined to the entire game once the radius is reduced to 1% and a cycle is completed in which no ANSP change the values of their decision variables. Since no ANSP or airline would find it worthwhile to deviate from the incumbent solution, this is deemed a Nash equilibria outcome. An outline of the local search algorithm is presented graphically in Figure 1.

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[6] A strategy is an action that a player could take which is composed of a set of decision variable values that is optimized according to an objective function. A mixed strategy also includes probabilities for playing a potential set of actions. A pure strategy is a limiting case of a mixed strategy whereby the probability of playing one of the actions is 1 and all the other actions receive a probability of 0. For more details see Gibbons (1992)[22].

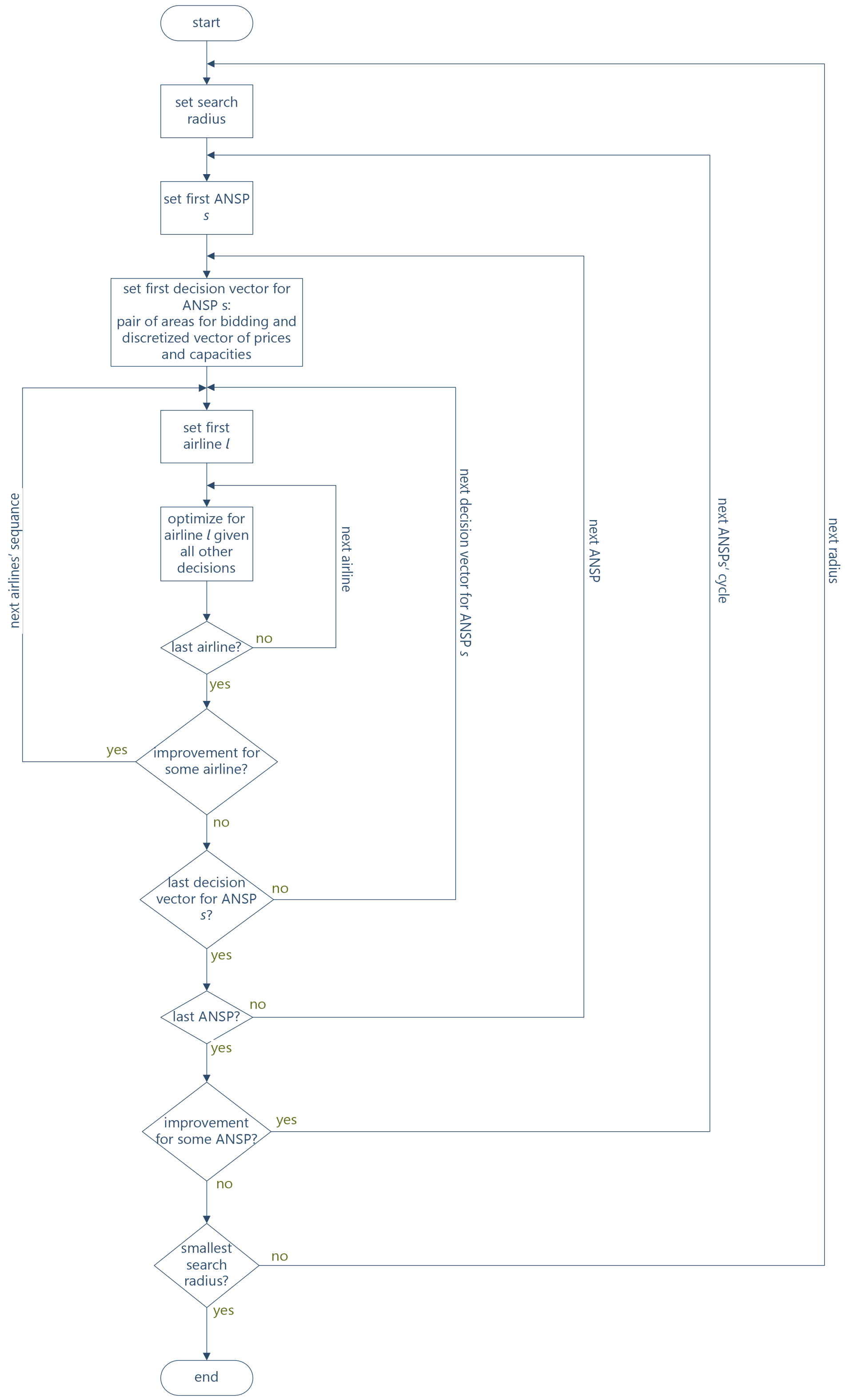

Figure 2: Algorithm to solve two-stage game

3 Case Study: Air Traffic Control in Western Europe

In this section, we first describe the network to be analysed, then the ANSPs and airlines that are considered within the game and finally the demand predictions assumed for analysis of years 2035 and 2050.

3.1 Network

The network analysed is depicted in Figure 2 and includes six ANSPs, represented by the coloured arcs, six major airports in each of the six regions, three regional airports and four additional nodes (yellow arrows) to aggregate flights to and from the region. According to the notation, $\boldsymbol{P}$ (and $\boldsymbol{B}^{P}$) represents the set of airports (and terminal towers) that are defined as red ovals on the map, and $\boldsymbol{T}$ is the set of transit nodes denoted as green diamonds on the map. $\boldsymbol{B}^{E}$ (and $\boldsymbol{A}_{b}$) is the partition of airspaces (and arcs) along Member State borders and defined as a coloured arrow in the map, with each of six colours representing the six countries analysed in the case study. Despite this being a clear simplification of reality, the network game should be sufficiently rich as to enable us to understand how the players will react to changes in institutional or regulatory rules, but simple enough to present results clearly.

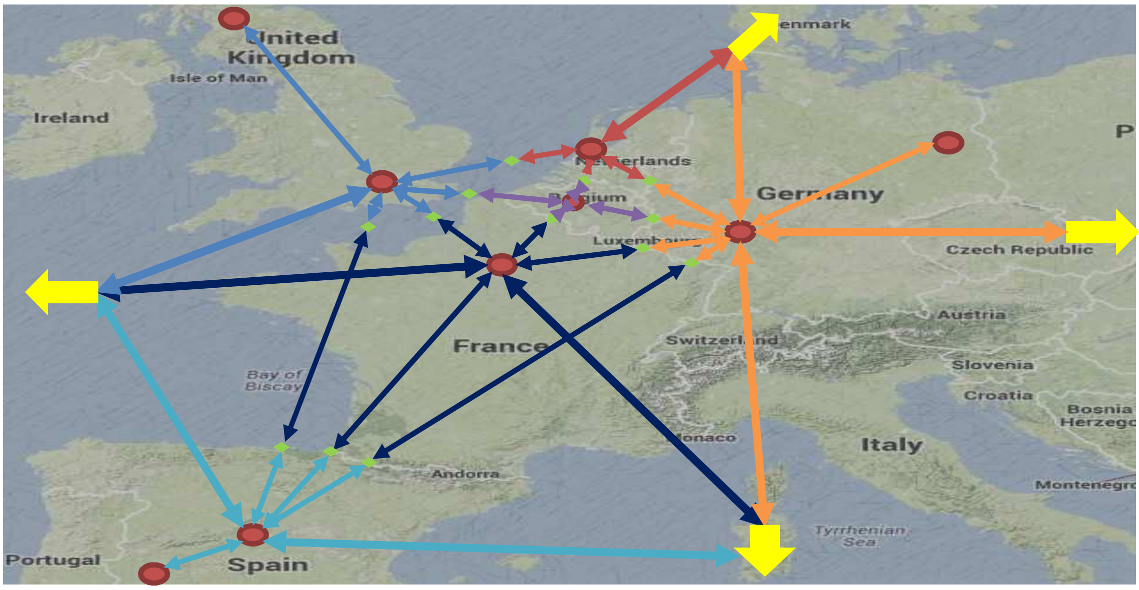

Figure 3: European air traffic control network case study

3.2 Air Traffic Control Providers

We focus on six ANSPs and collected data on ENAIRE (Spain), Belgocontrol (Belgium), DFS (Germany), DSNA (France), LVNL (Netherlands) and NATS (UK). In addition we also include the Maastricht Upper Airspace Control Centre (MUAC), which is in charge of the upper airspace (above 24,500 feet) in Belgium, Luxembourg, the Netherlands and Northwest Germany. MUAC acts on behalf of these ANSPs but the airlines are charged by the individual ANSPs through Eurocontrol, hence this activity has been included as if the ANSPs were providing the service[7]. In 2014, according to the ATM Cost-Effectiveness 2016 Benchmarking Report (Eurocontrol, 2016a[19]), these ANSPs were responsible for 47.4% of European traffic (in terms of flight hours controlled) and 54.0% of total en-route ATM/CNS costs. Eurocontrol's performance review unit also publishes the en-route ATFM delay minutes per ANSP and their costs which are based on the Cook and Tanner study (2015)[14]. Out of the total European ATM system, 58% of the delay minutes were attributed to the ANSPs in

[7] MUAC is monitored in the Eurocontrol (2016a) reports[19] and we split the variables across the three countries according to their relative size.

this case study. Consequently, the total costs to the airlines flying in the relevant airspace as a result of these delays amounted to €988 million which mostly draws from additional fuel burn and crew costs. Real delay costs may be substantially higher were consumer loss and schedule delay to be considered within this analysis. Based on the data collected from the Performance Review Reports, Table 1 summarizes the parameters applied in the first stage of the network congestion model. Staff and other operating costs constitute the variable, labour costs whereas depreciation, capital and exceptional items were classified as technology costs.

Table 1: 2014 En-route Air Navigation Service Provision Data

ANSP	Number of ATCOs	Variable Costs (000 €)	Technology Costs (000 €)	Total IFR controlled (km)	Income from charges (000 €)	Average Charge per km (€)
Parameters		$C_s^{S\lambda}$	C_s^{St}	k_b^0		τ_{sb}^0
NATS	926	439,427	188,703	798,501,566	780,462	0.98
LVNL	144	1,043,772	11,378	209,564,804	122,451	0.58
DFS	1,492	474,603	149,215	1,103,672,532	801,051	0.73
Belgocontrol	159	722,958	17,310	173,363,055	166,691	0.96
DSNA	1,448	574,512	127,025	1,542,050,584	1,200,520	0.78
ENAIRE	1,150	401,480	136,158	882,223,857	694,492	0.79

Source: Eurocontrol, 2016a[19]

When considering private for-profit or non-profit companies, we assume that the salaries and current expenditures on technology remain the same according to the location of the company i.e. the headquarters. The additional cost of new technologies and the benefits in terms of expanded capacities and reduced delays are drawn from the 2012 ATM Master Plan. Based on this plan, we have assumed that the technology costs to the ANSPs will double in order to achieve SESAR Step 1. Step 1 is expected to cost approximately €30 billion by 2030, of which the ANSPs are anticipated to cover 16% and the airlines 50% (additional costs are also attributed to the airports and other users). We assume that congestion en-route is reduced by approximately 27% and the operational costs to the airlines increase by a relatively small 0.1%, after accounting for the costs of the technology less the expected savings from reductions in fuel usage. For the ANSPs, we apply a production function that allows the company to trade-off capital and labour as specified in Deliverable 3.2 of COMPAIR.

The air traffic control terminal providers cover the nine airports included in Figure 2, however the data available from the Eurocontrol (2016a)[19] report is based on country level data as shown in Table 2. The fixed costs for countries with two airports in the case study were split based on their relevant proportions of activities.

Table 2: 2014 Terminal Air Traffic Control Data

Country	Number of ATCOs	Variable Costs (000 €)	Technology Costs (000 €)	Income from charges (000 €)	IFR airport movements	Avg. Charge per Movement (€)
Belgium	142	333,577	5,582	27,049	365,318	74.04
France	1334	163,694	33,731	236,532	1,821,345	129.87
Germany	403	432,717	30,175	232,612	1,947,971	119.41
Netherlands	114	433,974	3,996	56,372	496,588	113.52
Spain	629	224,766	28,460	164,402	1,282,703	128.17
UK	489	356,219	8,088	226,873	1,772,434	128.00

Source: Eurocontrol, 2016a[19]

The data presented in Tables 1 and 2 suggests that in certain countries, where the ANSP provides both en-route and airport terminal services, that some cross-subsidizing may occur, for example in Belgium. This is in accordance with the Commission Regulation (EC 1794/2006) which states in Charter I, article 3/3 that '*the costs of terminal services shall be financed by means of terminal charges imposed on the users of air navigation services and/or other revenues, including cross-subsidies in accordance with Community law*'. This decision is likely to impact the choice of investments expected to be implemented.

3.3 Airlines modelled in the network congestion game

Hundreds of airlines fly over European airspace providing both scheduled and charter services. For the sake of simplicity, we aggregate the airlines into three groups which best represent the structure of commercial aviation today. The groups cover airline alliances, low cost carriers and non-aligned carriers. The aligned airlines group is represented by three airlines: Lufthansa-Brussels (LH), British Airways-Iberia (BA) and Air France-KLM (AF), the main European airlines in the three airlines alliances that exist today. Each aligned airline is modelled with a two-hub system. LH utilizes Frankfurt and Brussels, BA utilizes London and Madrid whilst AF utilizes Paris and Amsterdam. For the purposes of this case, the low cost carrier group is represented by Easyjet (EJ) because the airline was ranked second amongst low cost carriers in terms of seat capacity in Western Europe in 2014. Ryanair is the largest carrier of this type but is deemed ultra-low cost which perhaps make it less representative of the low cost carrier group. Emirates airline was chosen as the representative carrier for the non-aligned carrier group. The Dubai based airline was ranked first among world airlines in terms of available seat kilometres in 2014 and Europe was their largest market based on seat capacity.

The airline groups achieve different costs levels which are mostly a direct function of the level of service they provide, output, network, average stage length and employment costs of the airlines' country of registration. There is a substantial difference in costs between the different airline groups; the cost per available seat kilometre for the aligned carriers in 2014 was approximately 8 euro cents, for Emirates it was 7 euro cents and for EasyJet it was 6.4 euro cents. Lufthansa has the highest variable cost, therefore is the first airline to respond to any increases in costs in the equilibria outcome. Table 3 summarizes the cost per available seat kilometres (CASK) for the airlines modelled.

Table 3: 2014 Airline data

Airline Group	% of fuel out of total expenses	CASK (€)
Star Alliance (Lufthansa AG) [8]	21.5%	0.088
Oneworld (British Airways) [9]	32.7%	0.075
SkyTeam (Air France-KLM) [10]	27.4%	0.069
Low Cost (EasyJet) [11]	31.7%	0.064
Emirates (Emirates) [12]	34.6%	0.071

Congestion impacts the cost categories to varying degrees. To be specific, the more indirect the flight path, the higher the fuel and staff costs for the airline and the higher the operating cost. We assume that the marginal congestion cost is linear in frequencies hence the total congestion cost increases in the square of frequencies. Indeed, the greater the delay in airspace, the higher the congestion costs for the airlines, which frequently amount to more than the air traffic control service charges (Ball et al. 2010[5], Cook and Tanner, 2015[13]). Congestion in air transport is caused in part by limited airport capacity, due to runway and terminal handling restrictions, and limited air traffic control capacity en-route. We assume that airport capacity is allocated efficiently across airlines by grandfathered but tradable slots. This better represents air traffic control congestion in Europe than in the US where aircraft are served for the most part on a first come, first served basis which creates higher demand for air traffic control in the peak period. Finally, the direct air traffic control user charges add an additional 6 to 12% to the airline operating costs[13]. It is standard practice for airline dispatchers to choose the flight path approximately four hours prior to the flight by balancing all the

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[8] Lufthansa Group Annual Report, Year ended December 31, 2014
[9] British Airways Annual Report and Accounts, Year ended December 31, 2014
[10] Air France-KLM Annual Financial Report 2014. Year ending December 31, 2014
[11] EasyJet Annual report and accounts 2014. Year ending September 30, 2014 Ex. Rate 1 GBP = 1.2849 Euro.
[12] The Emirates Group Annual Report 2014-15. Year ending March 31, 2015 Ex. Rate 1 United Arab Emirates Dirham = 0.2535 Euro.
[13] Normally, the shorter the average stage length, the relatively higher the percentage of air traffic control charges as a function of a carrier's direct operating costs (Swan and Adler, 2006)[39].

costs and accounting for potential weather disruptions for example. The flight path is then filed with Eurocontrol which, acting as the network manager, passes the information to the relevant ANSPs and to the Central Route Charges Office (CRCO) which in turn bills the airlines accordingly. We also include a revenue loss to airlines moving flights from the peak to off-peak in order to correctly balance the desire to avoid congestion and reduce costs yet meet passenger demand.

The airline demand is based on flight kilometres flown according to the Eurocontrol (2016a[19]) reports. The total demand was then split between the five companies such that the alliances utilise their hubs, the low cost carrier serves the secondary airports and traffic in each country and at each terminal approximates the 2014 movements. The airlines operating costs, C_l^O, were set at 85% of the values specified in Table 3, leaving an additional 10% value to be attributed to congestion, C_{lbw}^G, with the ANSP charges making up the remaining 5% approximately in the base run. The reduced revenue from flying during the off-peak, C_{lw}^R, was set at 50 euros per passenger (Swan and Adler, 2006)[39].

Finally, as stated in the section on ANSPs, we assume that the costs of SESAR Step 1 new technologies will cost approximately €30 billion by 2030, of which the airlines are expected to cover 50% according to the 2012 ATM Master Plan. We assume that congestion en-route is reduced by approximately 27% and that the operational costs to the airlines increase by a relatively small 0.1%, after accounting for the costs of the technology less the expected savings from reductions in fuel usage.

Two additional assumptions need to be specified in order to apply the model to the case study. First the demand function for flights between each origin-destination (OD) pair is set per airline, based on their scheduled timetable and an airline can decide to fly in the peak, to fly in the off peak or not to fly. The cost of not flying, the outside option C_{od}^T, is set at twenty times the sum of the ANSP charges for the least costly flight path from origin o to destination d because demand elasticity with respect to costs is considered to be relatively low. Given the fact that ANSP costs are approximately 5 to 8% of the airline's total operating cost, the likelihood of cancelling flights due to air traffic control costs is relatively low.

3.4 Demand Sub-Scenarios

In order to estimate potential equilibria outcomes in 2035 and 2050, as discussed in COMPAIR Deliverable 3.1 (Adler and Lithwick, 2017), we utilize the predicted IFR en-route and terminal movements as published in the Eurocontrol Challenges of Growth (2013) reports[17][18]. This data creates quite a large demand margin suggesting that by 2050, demand may be close to 2014 levels or alternatively, according to the global growth scenarios, may grow by more than 250%. The estimates are presented in Tables 4 to 7. In the scenarios, we analyse the global growth and the fragmented world demand forecasts in order to test the widest range of potential solutions.

Table 4: 2014 En-route IFR movements with predictions to 2035

ANSP	Total IFR controlled in 2014 (000 km)	expected IFR in 2035 (000 km)			
		Global growth (2.6% annually 2014-2035)	Regulated growth (1.8% annually 2014-2035)	Happy localism (1.6% annually 2014-2035)	Fragmenting world (0.7% annually 2014-2035)
Belgocontrol	173,363	297,202	252,151	241,949	200,713
DFS	1,103,673	1,892,060	1,605,253	1,540,310	1,277,789
DSNA	1,542,051	2,643,584	2,242,859	2,152,120	1,785,326
ENAIRE	882,224	1,512,423	1,283,164	1,231,251	1,021,404
LVNL	209,565	359,263	304,805	292,473	242,626
NATS	798,502	1,368,896	1,161,393	1,114,407	924,474
Compound growth		171%	145%	140%	116%

Sources: Eurocontrol, 2016a [19]and 2013a [17]

Table 5: 2014 En-route IFR movements with predictions to 2050

ANSP	Total IFR controlled in 2014 (000 km)	expected IFR in 2050 (000 km)			
		Global growth (2.8% annually 2035-2050)	Regulated growth (1.8% annually 2035-2050)	Happy localism (1.7% annually 2035-2050)	Fragmenting world (-0.4% annually 2035-2050)
Belgocontrol	173,363	449,726	329,516	311,558	189,002
DFS	1,103,673	2,863,067	2,097,781	1,983,455	1,203,231
DSNA	1,542,051	4,000,276	2,931,019	2,771,282	1,681,154
ENAIRE	882,224	2,288,601	1,676,868	1,585,481	961,807
LVNL	209,565	543,638	398,326	376,618	228,469
NATS	798,502	2,071,415	1,517,734	1,435,020	870,532
Compound growth		259%	190%	180%	109%

Sources: Eurocontrol, 2016a[19] and 2013b[18]

Table 6: 2014 Terminal airport movements with predictions to 2035

Country	IFR airport movements controlled by ANSP in 2014	expected IFR movements 2035			
		Global growth (2.6% annually 2014-2035)	Regulated growth (1.8% annually 2014-2035)	Happy localism (1.6% annually 2014-2035)	Fragmenting world (0.7% annually 2014-2035)
Belgium	365,318	626,276	531,342	509,846	422,951
France	1,821,345	3,122,387	2,649,083	2,541,910	2,108,682
Germany	1,947,971	3,339,466	2,833,256	2,718,632	2,255,285
Netherlands	496,588	851,316	722,270	693,049	574,930
Spain	1,282,703	2,198,977	1,865,647	1,790,169	1,485,063
UK	1,772,434	3,038,538	2,577,944	2,473,648	2,052,055

Sources: Eurocontrol, 2016a[19] and 2013a[17]

Table 7: 2014 Terminal airport movements with predictions to 2050

Country	IFR airport movements controlled by ANSP in 2014	expected IFR movements in 2050			
		Global growth (2.8% annually 2035-2050)	Regulated growth (1.8% annually 2035-2050)	Happy localism (1.7% annually 2035-2050)	Fragmenting world (-0.4% annually 2035-2050)
Belgium	365,318	947,681	694,370	656,528	398,272
France	1,821,345	4,724,801	3,461,882	3,273,214	1,985,643
Germany	1,947,971	5,053,285	3,702,563	3,500,779	2,123,692
Netherlands	496,588	1,288,213	943,879	892,439	541,384
Spain	1,282,703	3,327,495	2,438,070	2,305,198	1,398,412
UK	1,772,434	4,597,920	3,368,915	3,185,314	1,932,320

Sources: Eurocontrol, 2016a[19] and 2013b[18]

4 Case Study Results

In this section, we discuss the base-run results, which represent the transport equilibria outcome of model **(1)** and compare it to the results of the 2014 market for purposes of verification. Subsequently, we present the analysis with respect to for-profit companies defined in model **(2)** and the results of the non-profit corporation outlined in model **(3)**, first for the year 2014 and then the fragmented and global growth demand forecasts for 2035 and 2050.

4.1 Base-run Scenario

In this section, we estimate the behaviour of labour rent seeking ANSPs that are price capped and refer to this as the base-run. As shown in Table 8, the results of the mathematical analysis suggest that all ANSPs will charge according to the price cap in both peak and off-peak periods. The operating profit levels of the ANSPs are currently approximately 20% which is assumed in the base-run (Piers et al., 2017). The labour level decision variables are approximately equivalent to current staff levels and technology levels are also set at current levels (t=1). Consequently, the results of the base-run suggest that the ANSPs have no interest in investing in new technologies. The mix of current technologies and high labour levels creates more than sufficient capacity to meet the demand of 2014. Revenues and profits are at the expected levels for the six countries analysed and the airlines choose to serve all demand with CASKs similar to those reported in Table 3. Consequently, the modelling approach suggests that we are able to reproduce the 2014 transport equilibria outcome according to the assumptions described in Section II.

Table 8: ANSP charges, labour and technology levels and operating profits

Business as usual ANSPs	UK		Netherlands		Germany		Belgium		France		Spain		Labour	Tech level	Revenues (000 €)	Profits (000 €)
	Price in € per peak / off-peak per km															
NATS	1.11	1.11											605	1.00	737,598	283,054
LVNL			0.61	0.61									172	1.00	207,680	17,067
DFS					0.81	0.81							1,472	1.00	1,071,714	223,823
Belgocontrol							0.95	0.95					310	1.00	267,411	25,965
DSNA									0.81	0.81			2,442	1.00	1,720,356	190,538
ENAIRE											0.86	0.86	805	1.00	663,726	204,237
Annual Totals													5,806		4,668,486	944,683

4.2 For-profit scenario

If we assume that the ANSPs intend to maximise profits but are not required to participate in an auction, similar to the current situation in the United Kingdom, the results of the game are presented in Table 9. Labour levels are reduced substantially in favour of higher levels of technology for four of the six providers. However, two of the providers choose to purchase technology levels at close to the current transportation equilibria, suggesting that simply defining ANSPs as for-profit entities does not guarantee the adoption of new technologies alone. On the other hand, economic regulation remains very important in this scenario since all providers set their charges at the price cap both in the peak and the off-peak. Due to the reduction in capacities, close to the minimal levels set by the Member States, the ANSP profits have doubled compared to the base-run outcome.

Table 9: ANSP for-profits without tender

For profit **No tender** ANSPs	UK		Netherlands		Germany		Belgium		France		Spain		Labour	Tech level	Revenues (000 €)	Profits (000 €)
	Price in € per peak / off-peak per km															
NATS	1.11	1.11											486	1.09	716,431	296,770
LVNL			0.61	0.61									147	2.00	119,713	-56,455
DFS					0.81	0.81							832	2.00	1,123,545	430,170
Belgocontrol							0.95	0.95					184	2.00	245,849	77,849
DSNA									0.81	0.81			1,084	2.00	1,734,423	857,537
ENAIRE											0.86	0.85	408	1.16	563,417	241,705
Annual Totals													3,141		4,503,379	1,847,575

The outcome of the scenario in which governments introduce a tender system and ANSPs are modelled as for-profit entities is presented in Table 10. As a result of the auction, three companies each win two tenders, thus serving two of the countries in the case study. We note that when six companies participate in the auction, no equilibria outcome is found in the game. When twelve companies participate, the outcome is that three win service provision based on the lexicographic choice set of lowest peak price, followed by off-peak price, home bias and finally highest capacities. It is clearly important that sufficient companies participate in the auction in order to ensure an equilibrium outcome. We also note that we changed the lexicographic order and placed home bias first but this did not result in a different equilibria outcome.

Table 10: ANSP for-profits with tender

For-profit **2014** ANSPs	Price in € per peak / off-peak per seat per km												Labour	Tech level	Revenues (000 €)	Profits (000 €)
	UK		Netherlands		Germany		Belgium		France		Spain					
6. Germany			0.45	0.45	0.45	0.45							1,021	2.00	790,995	8,096
7. Belgium	0.32	0.32					0.49	0.49					276	2.00	243,748	9,242
10. France									0.29	0.29	0.43	0.43	1,219	2.00	999,481	44,963
Annual Totals													2,517		2,034,225	62,302

The results suggest that a German based company serves the Netherlands and Germany with a single unit charge across both airspaces. A Belgian company serves the UK and Belgium with Belgian airspace charges at a higher level than that of the UK. Although the two regions have a similar number of potential bidders, in this case the larger British market required a more competitive bid in order to win. The third, French company serves Spain and France with two separate charges. The reason that the French charge is lower than the Spanish charge is connected to the number of potential bidders in each of the airspaces. In Spain, we have assumed that only Spanish and French companies will bid (due to the contiguity constraints) whereas in France, five potential bidders exist (with headquarters located in Spain, the UK, Germany, Belgium and France). We note that in this equilibria, all three companies set peak and off-peak charges at the same level. We also note that overall, charge levels have reduced by approximately one half compared to the base-run (Table 8). The labour levels are halved as compared to the current level and SESAR technologies are adopted in full creating sufficient capacities to serve 2014 airline demand. **Consequently, this outcome achieves**

the two major policy preferences of the European Union; namely technology adoption and defragmentation of the Single European Skies. Furthermore, under this scenario it may be possible to reduce or remove economic regulation because the charges, an outcome of the bidding process, are halved in comparison to current levels and the companies achieve a profit of approximately 3% of operating income. We would suggest that if the number of competitive bids is lower, the charges are likely to increase but it is unlikely that they would double. However, it is clearly necessary to ensure an oligopolistic market with a reasonable number of potential actors for this result to hold over time, which is discussed further in Section 4.5.

For planning purposes, we test demand sub-scenarios for the fragmenting world and global growth demand forecasts indicated in Tables 4 and 5. Thus we span the potential outcome set from the two extreme cases in 2035 and 2050. In Table 11a, with an assumed potential demand growth of 16%, we see that the charges remain relatively stable, labour levels increase slightly and profits increase to 5%. In Table 11b, with a potential demand growth of 171% compared to 2014 levels, labour levels increase substantially and technology levels continue at *t*=2. Charges in the UK and the Netherlands increase by 12 and 30% respectively whereas charges in Spain drop by around 23% with the remainder showing relatively minor changes. The charge levels are a function of the number of competitors bidding, the size of the market in each airspace hence profitability potential and the relevant costs. Overall, profits increase to 23% which suggests that with expected global growth levels, there will be sufficient bidders in the market to ensure that profits are not too drastic in 2035.

Table 11a: ANSP for-profits with tender under fragmented 2035 demand

For-profit Fragment 2035 ANSPs	Price in € per peak / off-peak per seat per km												Labour	Tech level	Revenues (000 €)	Profits (000 €)
	UK		Netherlands		Germany		Belgium		France		Spain					
6. Germany			0.53	0.53	0.41	0.41							1,213	2.00	882,768	8,510
7. Belgium	0.31	0.31					0.44	0.44					375	2.00	329,232	23,470
10. France									0.32	0.32	0.38	0.38	1,062	2.00	938,640	74,614
Annual Totals													2,650		2,150,641	106,595

Table 11b: ANSP for-profits with tender under global 2035 demand

For-profit Global 2035 ANSPs	Price in € per peak / off-peak per seat per km: UK	Netherlands	Germany	Belgium	France	Spain	Labour	Tech level	Revenues (000 €)	Profits (000 €)
6. Germany		0.59 0.59	0.44 0.44				1,674	2.00	1,348,371	255,281
7. Belgium	0.36 0.36			0.51 0.51			422	2.00	458,814	118,795
10. France					0.27 0.27	0.33 0.33	1,890	2.00	1,374,732	34,607
Annual Totals							3,987		3,181,916	408,682

In Table 12a we present the results of sub-scenario fragmented world demand forecast for 2050 in which the Challenges for Growth (2013) report suggests that demand may fall by -0.4% between 2035 and 2050 leading to an overall demand increase of 9% compared to 2014 levels. In Table 12b we present the potential equilibria outcome under the global growth scenario in which traffic is expected to grow by 259% compared to 2014 levels.

Table 12a: ANSP for-profits with tender under fragmented 2050 demand

For-profit Fragment 2050 ANSPs	Price in € per peak / off-peak per seat per km: UK	Netherlands	Germany	Belgium	France	Spain	Labour	Tech level	Revenues (000 €)	Profits (000 €)
6. Germany		0.51 0.51	0.42 0.42				1,080	2.00	5,785,626	823,613
7. Belgium	0.35 0.35			0.36 0.36			246	2.00	1,955,553	214,359
10. France					0.28 0.28	0.41 0.41	1,182	2.00	9,255,637	962,229
Annual Totals							2,508		2,000,201	43,614

Perhaps unsurprisingly, the results in Table 12a are very similar to those of the base-run. On the other hand, the results in Table 12b have taken a long time to converge and the process suggests that there may be sufficient demand for four ANSPs to serve the market. Profits have risen specifically in Spain where charges rise substantially as a result of the lack of competition in this airspace. We draw the conclusion that it might be necessary to restrict charges in subsequent auctions should there be an insufficient number of bidders. This could be undertaken by capping the prices to the level of the previous bidding procedure.

Table 12b: ANSP for-profits with tender under global 2050 demand

For-profit Global 2050 ANSPs	Price in € per peak / off-peak per seat per km												Labour	Tech level	Revenues (000 €)	Profits (000 €)
	UK		Netherlands		Germany		Belgium		France		Spain					
6. Germany			0.42	0.42	0.55	0.55							2,457	2.00	2,191,505	727,025
7. Belgium	0.29	0.28					0.44	0.44					552	2.00	541,334	107,599
10. France									0.26	0.26	0.83	0.80	3,076	2.00	3,200,472	1,179,477
Annual Totals													6,085		5,933,310	2,014,101

In Table 13 we present summary information on the second-stage airline choices under three scenarios: the base-run, profit maximisers under auctions for 2014 and for 2035 assuming global growth demand levels. Peak demand at the six major airports are limited to 80% due to runway limitations and peak demand is close to the constraints. Under the auction system with lower charge levels, all airlines are better off and the CASKs are slightly reduced. The low cost carrier notably reacts by moving more flights into the off-peak in order to reduce congestion costs since capacity levels are one third lower under the auction system than under current levels. Indeed, within the auction system we determine a minimum capacity level demanded by the State in the auction process, below which the provider will pay a penalty. This would be the equivalent of setting a desirable maximum delay level as set by the Performance Review Board today. We note that without such a minimum level, the providers set very low levels of capacity. Under the 2035 global growth scenario, capacities increase but less than that of the demand and the result is that the low cost carrier pushes more movements into the off-peak in order to better manage congestion. The reason that the low cost carrier is the first to react to capacity levels is that all airlines lose revenues by serving demand in the off-peak but this a relatively lower burden on the low cost carriers since their airfares are relatively lower anyway (as are their costs).

Table 13: Airline costs per available seat kilometre across scenarios

	User Equilibrium business as usual			Profit Maximization under auctions			Profit Maximization under auctions global demand 2035		
Airlines	cask	peak %	offpeak %	cask	peak %	offpeak %	cask	peak %	offpeak %
LH	0.104	78	15	0.100	82	16	0.103	68	8
BA	0.089	81	18	0.085	81	19	0.088	80	17
AF	0.084	83	17	0.081	83	17	0.084	83	17
LC	0.073	87	13	0.069	74	26	0.070	36	64
Rest	0.083	87	9	0.080	87	12	0.082	86	13

Finally, we capped the air traffic control charges by half based on the result of the for-profit equilibria outcome but did not require a tender or competition in service. The result is presented in Table 14 and shows that the companies all achieve negative profits despite reducing labour levels to the minimum and for the most part, not investing in new technologies. The lack of ability to reduce costs by serving larger airspaces means that the additional technology is adopted in only one of the six countries. Clearly, such a position would be untenable in the long term since ANSPs would continue to build debt and the level of service to the airlines would restrict aircraft movements.

Table 14: ANSP for-profits without tender and halved price caps

Half price cap	Price in € per peak / off-peak per km												Labour	Tech level	Revenues (000 €)	Profits (000 €)
ANSPs	UK		Netherlands		Germany		Belgium		France		Spain					
NATS	0.56	0.56											253	1.00	193,351	(106,461)
LVNL			0.31	0.31									100	1.07	30,684	(85,882)
DFS					0.41	0.41							334	1.02	157,076	(154,306)
Belgocontrol							0.48	0.48					103	2.00	76,990	(31,964)
DSNA									0.41	0.41			312	1.36	222,499	(128,981)
ENAIRE											0.44	0.44	131	1.00	103,409	(85,452)
Annual Totals													1,233		784,009	(593,047)

4.3 Non-profit scenario

We investigate the possibility of defining ANSPs as non-profit entities, similar to the Canadian approach, but also participating in auctions. The equilibria outcome leads to four companies winning auctions as compared to three in the for-profit scenario. The result achieves lower economies of scale than the for-profit outcome and substantially higher prices in most countries, although less than the current price cap. In particular, the UK provider serves only British airspace and offers a significantly lower charge in the off-peak. On the other hand, many bids for the Dutch airspace lead to a low charge which is slightly cross-subsidized by the winning German company that also serves German airspace. The adoption of new technologies is sporadic with two companies employing SESAR technologies, one utilizing half the capabilities and the UK company avoiding their use entirely. We note that overall revenues are slightly lower and profits are very low as compared to the for-profit case. This is partially due to the lower capacity levels offered which is a result of the objective function to maximise capacity but also to minimize profits. The equilibria outcome is thus a mix of the current situation and the for-profit scenario with some defragmentation of the skies and employment of new technologies where labour wages are relatively high. However, this equilibrium is not stable because the Belgian company is making losses and would either need a bailout in the longer term from the Belgian government or a new tender would need to be organized.

Table 15: ANSP non-profits with tender

Non-profit 2014 ANSPs	Price in € per peak / off-peak per km												Labour	Tech level	Revenues (000€)	Profits (000 €)
	UK		Netherlands		Germany		Belgium		France		Spain					
1 UK	1.01	0.79											295	1.00	318,158	31
5 Germany			0.15	0.15	0.81	0.76							625	1.92	583,224	497
7 Belgium							0.81	0.81					100	1.53	98,413	(408)
10 France									0.24	0.24	0.75	0.75	939	2.00	794,344	953
Annual Totals													1,959		1,794,139	1,073

In Tables 16a and 16b we present the demand sub-scenarios for 2035 and in Tables 17a and 17b the equivalent for 2050. The result in Table 16a is the most stable of all outcomes with three companies winning bids and all achieving positive profits. The charges are lower than those currently in place but higher than the for-profit equilibria outcomes. Labour levels are relatively low but higher than the for-profit scenarios. Technology adoption levels are mixed because the larger non-profit

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companies in general adopt Step 1 targets but the smaller companies do not. If four companies are left serving the market, the two smallest that each serve a single airspace set charges close to the current price cap and fail to adopt technologies. Clearly, the non-profit companies with the dual purpose of maximising capacity and achieving no profits have difficulties finding the optimal levels of each and this may be indicative of real-world non-profits. However, we also note that MUAC is a relatively cost efficient ANSP and has non-profit status (COMPAIR deliverable 3.2 (Adler et al., 2017[3])). MUAC is clearly a special case because their customers are the ANSPs rather than the airline operators.

Table 16a: ANSP non-profits with tender under fragmented 2035 demand

Non-profit **Fragment 2035** ANSPs	Price in € per peak / off-peak per km												Labour	Tech level	Revenues (000€)	Profits (000 €)
	UK		Netherlands		Germany		Belgium		France		Spain					
1 UK	0.48	0.48					0.69	0.69					547	1.23	475,948	4,043
5 Germany			0.23	0.23	0.78	0.78							675	2.00	619,366	430
10 France									0.24	0.24	0.75	0.75	1,012	2.00	840,935	5,419
Annual Totals													2,234		1,936,249	9,892

Table 16b: ANSP non-profits with tender under global 2035 demand

Non-profit **Global 2035** ANSPs	Price in € per peak / off-peak per km												Labour	Tech level	Revenues (000€)	Profits (000 €)
	UK		Netherlands		Germany		Belgium		France		Spain					
1 UK	0.91	0.91											429	1.00	390,561	13,188
2 UK			0.21	0.21									161	1.00	(17,049)	(276,529)
10 Germany					0.71	0.71	0.71	0.71					662	2.00	616,582	3,994
11 France									0.24	0.24	0.86	0.75	1,310	2.00	992,214	(14,295)
Annual Totals													2,562		1,982,308	(273,642)

Table 17a: ANSP non-profits with tender under fragmented 2050 demand

Non-profit **Fragment 2050** ANSPs	Price in € per peak / off-peak per km												Labour	Tech level	Revenues (000€)	Profits (000 €)
	UK		Netherlands		Germany		Belgium		France		Spain					
1 UK	0.98	0.98	0.22	0.22									542	1.22	468,249	359
5 Germany					0.81	0.81	0.51	0.51					560	1.72	519,940	(1,915)
10 France									0.24	0.24	0.86	0.75	937	2.00	790,168	(2,095)
Annual Totals													2,039		1,778,358	(3,651)

Table 17b: ANSP non-profits with tender under global 2050 demand

Non-profit **Global 2050** ANSPs	Price in € per peak / off-peak per km												Labour	Tech level	Revenues (000€)	Profits (000 €)
	UK		Netherlands		Germany		Belgium		France		Spain					
1 UK	0.94	0.94											462	1.04	378,793	(20,205)
5 Germany					0.81	0.71	0.80	0.80					786	2.00	682,868	11,276
7 France			0.12	0.12									101	2.00	(24,000)	(131,536)
10 France									0.26	0.26	0.83	0.83	1,488	2.00	1,114,328	5,520
Annual Totals													2,837		2,151,990	(134,945)

Finally, we tested the potential outcome were non-profits to serve the market without an auction, as occurs today in Canada and Switzerland. The results are presented in Table 18 and show that in four of the six countries the charges are set below current levels and that new technologies would be adopted in four of the six countries. Overall, this solution would appear to be preferable to a for-profit, no auction system as is currently the case in the United Kingdom. However, we note that there is the possibility that losses, in the region of 5% of revenues, could cause issues over time.

Table 18: ANSP non-profits without tender

Non profit No tender ANSPs	Price in € per peak / off-peak per km UK		Netherlands		Germany		Belgium		France		Spain		Labour	Tech level	Revenues (000 €)	Profits (000 €)
NATS	0.83	0.83											277	1.00	308,505	(1,739)
LVNL			0.61	0.61									231	2.00	210,092	(53,533)
DFS					0.61	0.61							597	1.83	533,629	(23,154)
Belgocontrol							0.95	0.95					274	2.00	211,654	(21,224)
DSNA									0.61	0.61			487	2.00	498,883	(34,898)
ENAIRE											0.64	0.64	206	1.00	218,833	(65)
Annual Totals													2,072		1,981,597	(134,613)

4.4 Summary of results of scenarios analysed

Table 19: Summary of all scenarios

Scenario	Year	# of providers	Peak price per km in €			off-peak price per km in €			ATCO	Tech level			Annual total revenues (000 €)	Annual total profits (000 €)
			Avg.	Min	Max	Avg.	Min	Max		Avg.	Min	Max		
Without tenders:														
Base-run	2014	6	0.86	0.61	1.11	0.86	0.61	1.11	5,806	1.00	1.00	1.00	4,668,486	944,683
For-profit	2014	6	0.86	0.61	1.11	0.86	0.61	1.11	1,233	1.71	1.09	2.00	4,503,379	1,847,575
Non-profit	2014	6	0.71	0.61	0.95	0.71	0.61	0.95	2,072	1.64	1.00	2.00	1,981,597	(134,613)
For-profit halved price caps	2014	6	0.44	0.31	0.56	0.44	0.31	0.56	1,233	1.24	1.00	2.00	784,009	(593,047)
With tenders:														
For-profit	2014	3	0.41	0.29	0.49	0.41	0.29	0.49	2,517	2.00	2.00	2.00	2,034,225	62,302
Non-profit	2014	4	0.63	0.15	1.01	0.58	0.15	0.81	1,959	1.61	1.00	2.00	1,794,139	1,073
For-profit fragmented	2035	3	0.40	0.31	0.53	0.40	0.31	0.53	2,650	2.00	2.00	2.00	2,150,641	106,595
Non-profit fragmented	2035	3	0.53	0.23	0.78	0.53	0.23	0.78	2,234	1.74	1.23	2.00	1,936,249	9,892
For-profit global	2035	3	0.42	0.27	0.59	0.42	0.27	0.59	3,987	2.00	2.00	2.00	3,181,916	408,682
Non-profit global	2035	4	0.61	0.21	0.91	0.59	0.21	0.91	2,562	1.50	1.00	2.00	1,982,308	(273,642)
For-profit fragmented	2050	3	0.39	0.28	0.51	0.39	0.28	0.51	2,508	2.00	2.00	2.00	2,000,201	43,614
Non-profit fragmented	2050	3	0.60	0.22	0.98	0.59	0.22	0.98	2,039	1.65	1.22	2.00	1,778,358	(3,651)
For-profit global	2050	3	0.47	0.26	0.83	0.46	0.26	0.80	6,085	2.00	2.00	2.00	5,933,310	2,014,101
Non-profit global	2050	4	0.63	0.12	0.94	0.61	0.12	0.94	2,837	1.76	1.04	2.00	2,151,990	(134,945)

4.5 Second round bidding process

Within five to ten years, the auction should be repeated in order to encourage potential entry of new, more efficient firms. The Commission Regulation (EU 391/2013) put forward three points to ensure the easier entry of newcomers: (1) equipment can be easily transferred to a newcomer; (2) no qualifications that easily block entry e.g. ten years prior experience; and (3) transparency in the accounting system such that a newcomer does not face a large asymmetry of information. Consequently, the air control centre buildings should perhaps belong to the government rather than the operator and the Performance Review Unit should continue to produce annual, audited reports. The European Commission has already defined the conditions necessary to open the market for tower control in Annex 1 of Commission Regulation (EC) No 1794/2006. The UK Civil Aviation Authority has written a review (CAP 1293) which specifies how to check the five criteria on market conditions set according to the Regulation. Williamson (1976) states that the threat of exit might affect a firm's incentive to invest in long term assets and equipment unless there is a guaranteed opportunity of selling the asset at an appropriate price if and when necessary. Therefore, the length of the tender should match the timeframe of software support which is on average seven years currently.

In order to shed light on the question of bidding over time, we model a second round bidding process with the three companies that won the first round (Table 10). The equilibria outcome shows similar levels of production but charges that returned to the pre-auction price cap level. Consequently, it is clear that an insufficient number of bidders will lead to higher charges. If we assume one potential new entrant in each of the auctions, this would be sufficient to ensure that the revenue streams remain stable, as shown in Table 20. The assumption here is that in the second round there will be six bidders, three incumbents from the first round plus three new entrants. The results in the second tender are almost identical to those of the first tender, thanks to the potential competition for the market from the three new entrants. Alternatively, in the case of insufficient bids, the Member States could connect price bids to the values set in the previous auctions.

Table 20: ANSP for-profits with tender and 6 firms bidding

For-profit **2nd round bid** ANSPs	Price in € per peak / off-peak per seat per km												Labour	Tech level	Revenues (000 €)	Profits (000 €)
	UK		Netherlands		Germany		Belgium		France		Spain					
6. Germany			0.45	0.45	0.45	0.45							1,021	2.00	790,952	8,053
7. Belgium	0.31	0.31					0.47	0.47					276	2.00	235,216	710
10. France									0.28	0.28	0.42	0.42	1,219	2.00	969,282	14,764
Annual Totals													2,517		1,995,450	23,527

5 Conclusions and Future Research

Introducing an auction system at the level of each European State would be one means to creating competition for the market. A regular auctioning system may help to achieve a number of aims of the European Union embodied in the Single European Skies (SES) initiative. The major aims of the SES include a reduction in costs via defragmentation and increases in capacity offered via adoption of new technologies.

In this research we have developed and applied a game-theoretic formulation in order to analyse the air traffic management market in Europe. We assume that Member States retain the choice to decide whether or not to introduce an auction in order to tender out the service to either for-profit or non-profit companies. The governments' may also choose the minimum level of service required, the length of the tender, whether a company is allowed to adapt charges should SESAR technologies be adopted and whether the company will pay a penalty if they fail to meet the service level defined. The two-stage game is based on a network congestion sub-game perfect Nash equilibrium whereby the ANSPs behave according to their objective function and bid for multiple airspaces. In the second stage, airlines choose their flight paths such that they minimize their costs given a pre-defined schedule. Airlines take into account five operational costs, all of which are impacted by the air traffic control companies to a certain degree. All of the data applied in the case study draws from publicly available datasets and the only parameter that is unknown is the elasticity of the airlines to large changes in the ANSP charges. We assume that the airline elasticity is relatively low because the air traffic control charges represent a small percentage of the total airline costs. We analyse a case study composed of six West European countries because they represent 50% of the air traffic served in Europe whilst reducing the number of companies modelled mathematically. We assume that the remaining set of providers would behave in a similar way to the six tested directly.

The creation of for-profit ANSP companies and the introduction of competitive tendering processes would likely lead to the defragmentation of the skies because companies would bid for more than one airspace. Such a tender system would also lead to lower charges than occurs today, in part due to the economies of scale achieved through defragmentation and in part due to the bidding process that creates a competitive environment at least once every five to ten years. Another advantage of this system would be the potential to remove the economic regulatory bodies currently involved in setting the price caps of the existing system. Based on the results of the analysis, it would likewise appear that another aim of the single skies initiative could be achieved, namely adoption of new SESAR technologies.

In this research, we similarly analyse the potential to replace the current system with non-profit organizations of the type created in Canada with airlines on the management board. However, as opposed to the Canadian system, we test the likely outcome were the non-profits to participate in a competitive tendering process. The non-profit organisations suffer from a less clear mandate than that of the for-profit companies. We define their objective function as balancing charges to earn little to no profit and maximising capacity. The equilibria outcome lies in-between the current solution and that of the for-profit scenario. The non-profits would lead to defragmentation of the skies although possibly to a lesser extent than that of the for-profits. New technologies would be partially adopted only and mainly by the larger companies and charges, although lower than the current price caps, are higher than that of the for-profit solution outcome in most cases. We do note, however, that if auctions are not introduced then partial aims of the SES are more likely to be achieved through non-profits than through a series of non-competitive, for-profit companies.

Based on a series of sensitivity analyses, it is clear that in a competitive scenario there will be substantial pressure to reduce capacities, hence the auction requirements would need to set minimum levels in the bid process. It would also be necessary to track the progress of the companies in order to ensure that the service level targets are indeed met. Creating a peak and off-peak pricing system that is also dependent on service levels, as occurs today in the UK, may help to encourage the companies to produce sufficient service levels such that congestion and delays would be less of an issue. Regulatory bodies involved in measuring delay levels and safety levels would clearly need to continue in their current roles.

The obvious question that arises is whether the gains from the first round of auctions could be sustained in subsequent rounds, five to ten years later. Clearly, it would be important to ensure sufficient bidders over time. This may be accomplished by setting a maximum number of auctions across Europe in which a company may bid or alternatively, by setting a maximum market share. A minimum of two bidders in subsequent rounds would be necessary, not to ensure cost efficiency or technology adoption, rather to ensure that the charges do not return to their pre-competitive levels. We would argue that provided the entry barriers to bid are not excessive, such a level of competition is possible over time. However, in the case of insufficient bids, it may be reasonable to add a restriction in the auction that charges set in the previous round act as a reference point in the new round.

Future research is related to the assumptions and limitations of the current modelling. The analysis is based on publicly available data. For example, should more detailed information with respect to the cost functions of ANSPs or the impact of technologies be available, this may increase the accuracy of improve the analysis. However, it would probably not alter the results. It may also be of interest to extend the analysis to cover the whole of Europe although some time would need to be invested in solving the large scale optimization problems involved. It may also be of substantial interest to consider an extension of the model to include a cost-benefit analysis that would combine the charges, the labour and technology levels and capacity and delay levels in order to determine the preferable scenario from an individual Member State perspective and a pan-European perspective with respect to overall social welfare. Finally, the game theoretic analysis presented here is static and a dynamic form may provide greater insight into issues surrounding the impact of auctions over time.

6 References

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