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COMPAIR

COMPETITION FOR AIR TRAFFIC MANAGEMENT

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Abstract

This report summarizes the main conclusions from two modelling approaches which were developed in order to assess the potential impact of introducing competition to the Air Traffic Management system. We highlight the main insights and policy recommendations that follow from the model development stage. Conclusions are drawn as to the most appropriate competitive forms that will help the aviation market move towards the goals set out in the Flightpath 2050 document.

The results of both models suggest that introducing competition for the market via outsourcing service provision may lead to a reduction in charges by up to half the current levels. It would also appear that auctioning the service is likely to encourage defragmentation of the European system because companies may win more than one auction. According to the agent-based simulation, the results suggest that a maximum market share of 40% ensures sufficient competition. The companies will be large enough with sufficient financial backing that they will be in a position to invest in new SESAR technologies. Both modeling approaches derive results suggesting that for-profit companies are highly likely to invest in such technologies thus encouraging 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. Finally, according to the game-theoretic model, non-profit companies would be strictly preferable to both the current state agency and to a government corporation if auctions are not introduced.

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Context

The COMPAIR project discusses potential options for introducing a variety of forms of competition into the air traffic control management system. An auctioning system is one potential form that may help to achieve a number of aims of the European Union embodied in the Single European Skies initiative. The major aims of the initiative include a reduction in costs via defragmentation and an increase in capacity offered via the adoption of new technologies.

Objectives and Methodology

In this research, we have developed two different quantitative approaches, one based on game-theoretic concepts (Deliverable 4.1) and the other on agent-based simulation (Deliverable 4.2). The aim of both modelling approaches is to understand the potential impact of auctioning air traffic control management services in each Member State (competition for the market) and the outcome of a hypothetical sector-less scenario in which ANSPs provide air navigation services to flights from origin to destination (competition in the market)..

Within the game-theoretic model, we develop a two-stage game with multiple actors in each stage. The air traffic control companies set their charges (which may be price capped) and capacities in the first stage and the airlines respond in a second stage by choosing flight paths that minimize their costs. We define a network of flight paths and based on airline demand and air traffic control capacities, consider congestion and its impact on airline costs. We subsequently estimate a Nash equilibria outcome which means that we search for a set of decisions for all players such that no player could change their mind and be better off. To be more specific, in stage zero, the Member State regulator creates a specific scenario, such as a tender system, which is then analysed. The first stage of the game describes the air traffic control service providers who set their charges and capacities and bid for one or more airspaces. In various scenarios, different provider types are modelled, including the current government-owned organizations, non-profit organization similar to the Nav Canada model and for-profit companies, similar to the Swedish Aviation Capacity Resources company and the DFS subsidiary, Air Navigation Solutions Ltd. In stage two, the airline operators choose their flight paths given the first stage decisions of the ANSPs, which impact the choice of technology employed, congestion levels and the air traffic control charges. A sub-game perfect equilibria is sought such that no stakeholder would deviate from their choices i.e. a Nash equilibria. The static game is assessed for the years 2014, 2035 and 2050 in an attempt to understand the impact of changes in demand on the likely market outcome.

An agent-based model evaluates the outcome of two different institutional designs: (i) the tendering of licenses to operate en-route air traffic services in specific geographical areas and (ii) the provision of en-route air traffic services on a sector-less origin-destination pair basis. The agent-based simulation is comprised of three main elements; (1) geographical context, which provides the environment for the agents to operate in, (2) agents, including the regulator, the ANSPs and an airline, and (3) exogenous variables, which represent external conditions that affect the model but are not affected by it. The model which evaluates the tendering of licenses to operate en-route air traffic services in specific geographical areas consists of two stages. The first stage simulates the tendering process, in which ANSPs compete for the control of different geographical areas. In this stage, only the regulator and the ANSPs participate. ANSPs submit a certain unit rate per service unit per area that will be the maximum unit rate applicable in that area during the license period. Contract conditions in the tendering process include the minimal capacity the ANSPs must provide during the license period and the maximum market share an ANSP may handle due to competition regulation, in order to avoid monopolistic behaviour. The second stage simulates how agents evolve between auctions. In this stage, an airline aims to meet total passenger demand and react to the ANSPs decisions by choosing different routes according to the air navigation charges applied by the ANSPs in each geographical zone. Charges are adjusted every given period of time until the license period is over. Once the license period expires, the tendering process is repeated. This could lead to contract renewal for the incumbent provider or to an alternative incumbent. The simulation is finished when the temporal horizon is reached and assessments have been made running from 2014 to 2050. The second model analyses a futuristic sector-less scenario in which ANSPs provide air navigation services to flights from origin to destination. To explore this idea in a simple manner, we have simulated a market design similar to the electricity market, in which airlines submit their bids and ANSPs simultaneously submit their ask prices of controlled flight-kilometres to a Regulator agent, which chooses some price p that clears the market. The model simulates a group of ANSPs competing in the market to maximise their profit and an Airline agent which responds to the charges of ANSPs. The model has been applied to a simplified scenario which reproduces the provision of en-route services in Western Europe and illustrates the effect that the ANSPs' parameters and the maximum allowed market share have on the outcome.

Findings

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 multiple analyses, it would likewise appear that another aim of the single skies initiative could be achieved, namely the 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, mainly by the larger companies, and charges would be lower than the current price caps but 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 charging system that is 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 results of the agent-based simulation concerning the tendering of licenses to provide en-route air traffic services in specific geographical areas suggest that one of the main factors that drives the effectiveness of the ANSPs is the bidding strategy they follow. In the short and medium-term it seems that conservative strategies perform better in terms of profit, despite having a lower market share. Nevertheless, in the long-term, the most aggressive strategy is demonstrated to be the dominant strategy. It also demonstrates that the ANSPs controlling the biggest countries when liberalising the market have an advantage due to their higher potential to invest in new technology and the economies of scale. With regard to the auction parameters, the scenarios evaluated proved that the main parameter which influences the outcome of the tendering both in the charges and the market share of the ANSPs is the maximum allowed market share established by the competition regulation: increasing the maximum market share permitted favours the existence of relatively larger ANSPs which are in a better position to attain economies of scale, but may lead to restricted levels of competition in the longer term. The order in which the Member States undertake the auctions has a strong impact on the local charges in each country, but the global network effect is not as important. Member States adopting the auctioning system earlier are at an advantage. Finally, the duration of licenses shows different outcomes but there is not a clear evidence to assert which one would lead to better results in the long-term.

In the case of the sector-less scenario, with air traffic services provided on an origin-destination pair basis, we observe that the most important parameter of ANSPs is their productivity, as the most productive ANSPs perform better during the simulation regardless of their size. This is due to their ability of bidding lower charges, which ensures them some profit in every time step. However, less efficient ANSPs cannot submit competitive bids and they end up being out of the market. Regarding the maximum market share allowed, the model suggests that, since the dominant ANSPs tend to increase their market share in each auctioning process, the maximum market share permitted is a necessary measure in order to avoid the emergence of a monopolistic ANSP serving the entire European market.

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 management system. In this summary, we first describe the two approaches developed in order to assess potential competition for the market based on game theory and agent based simulation. Then in Section 3, we draw conclusions from the results analysed in each of the case studies. We note that the two approaches are very different from both a mathematical perspective as from the case studies analysed. Yet the conclusions from these approaches are surprisingly similar. Introducing competition through the auctioning of the services will likely lead to defragmentation of the market, which permits substantial economies of scale. The competitive process will also lead to the ANSP companies potentially reducing their charges by as much as half and reducing or removing the need for economic regulation. Finally, privatized air navigation service providers are more likely to invest in SESAR technologies, which would further improve capacities to the benefit of passengers, airlines and airports.

1.1 Delivery objective

This deliverable describes two quantitative approaches which assess the potential impact of outsourcing air navigation service provision –both on a country basis as on OD basis in place of the current system. General conclusions are drawn as to the potential to defragment the market and encourage the adoption of new technologies simultaneously.

1.2 Intended readership

This deliverable is meant to be open to the public for anyone interested in the European ANSP market. It is a non-technical summary of Deliverables D4.1 and D4.2 of the COMPAIR project.

2 Modelling approaches

The two modelling approaches developed for COMPAIR are intended to throw light on the likely impacts of introducing competition for the air traffic control market. We apply two different approaches to analyse the potential outcomes. The major questions to be answered include the following:

i) What should the rules of such an auction be?

ii) Would the goals of the Single European Skies initiative be achieved?

iii) Would an auctioning system continue to achieve the goals over time?

iv) Is there a preferable ownership form of air traffic control companies?

v) With entirely new sector-less technologies, how would the market develop?

In section 2.1 we discuss the game-theoretic approach and in section 2.2 we present the agent-based simulation approach. The agent-based simulation discusses both the tendering of licenses and a more forward-looking scenario in which air traffic control services are provided on a sector-less origin-destination basis. Conclusions to these questions are drawn in Section 3.

2.1 Game-theoretic 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. Stage zero defines the decisions of the Member State regulator, which are set exogenously prior to analysing the game, hence creating a specific scenario. Each government chooses whether to contract out the service and sets minimum acceptable service levels. 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. The government may also choose to set bonus and penalty systems with respect to service levels in the auction requirements. The first stage of the game describes the air traffic control service providers who set their charges and capacities and bid for one or more airspaces. In stage two, the airline operators choose their flight paths given the first stage decisions of the ANSPs.

We assume that within each auction, the bidders i.e. ANSP companies, 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 a case study 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 in the case study 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. A peak price should cover the times during which congestion is an issue, which may be during morning and early evening peaks, or separate day versus night times. If the provider offers a service level higher than the minimum, the charge per km increases as occurs today in the UK[1]. 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 either labour rent maximisers, private company profit maximisers or not-for-profit capacity maximisers. Each service provider best responds to the choices of its competitors, taking as given the equilibrium airline service flows that will be chosen by the airline operators in the second stage of the game, thus leading to a sub-game perfect Nash equilibrium. This equilibria

[1] Civil Aviation Authority Report in 2015: https://publicapps.caa.co.uk/docs/33/CAP1252_Decision_RP2.pdf

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.

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). Scenario 2 defines a profit maximisation objective function per service provider. 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. Scenario 3 defines a non-profit ANSP company that maximises capacity and minimises profits simultaneously, with the same costs and revenue functions described in Scenario 2.

In the second stage of the game, 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 are composed of five categories, all of which are impacted to some degree by the service providers. Their cost function includes (1) operating costs, (2) costs from flying off-peak equivalent to the loss of revenues due to lower airfares charged in the off-peak, (3) congestion costs, (4) ANSP charges and (5) costs for not flying or cancellations. In order to account for elastic demand, there exists an outside option flow which represents the choice to reduce service, 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 airline operating and congestion costs are a function of SESAR1 technologies employed, as outlined in detail in the SESAR 2012 ATM Master Plan. The level of technologies employed is determined by the winning ANSP in the first stage. Based on the results of a coordination game (Osborne and Rubinstein, 1994), we assume that once the ANSP has chosen to invest in technology, the airlines will follow suit since it is in their financial interest to do so. 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 considers only its own congestion costs and ignores the external congestion costs imposed on the other airlines. The organization of the game is defined in Figure 1.

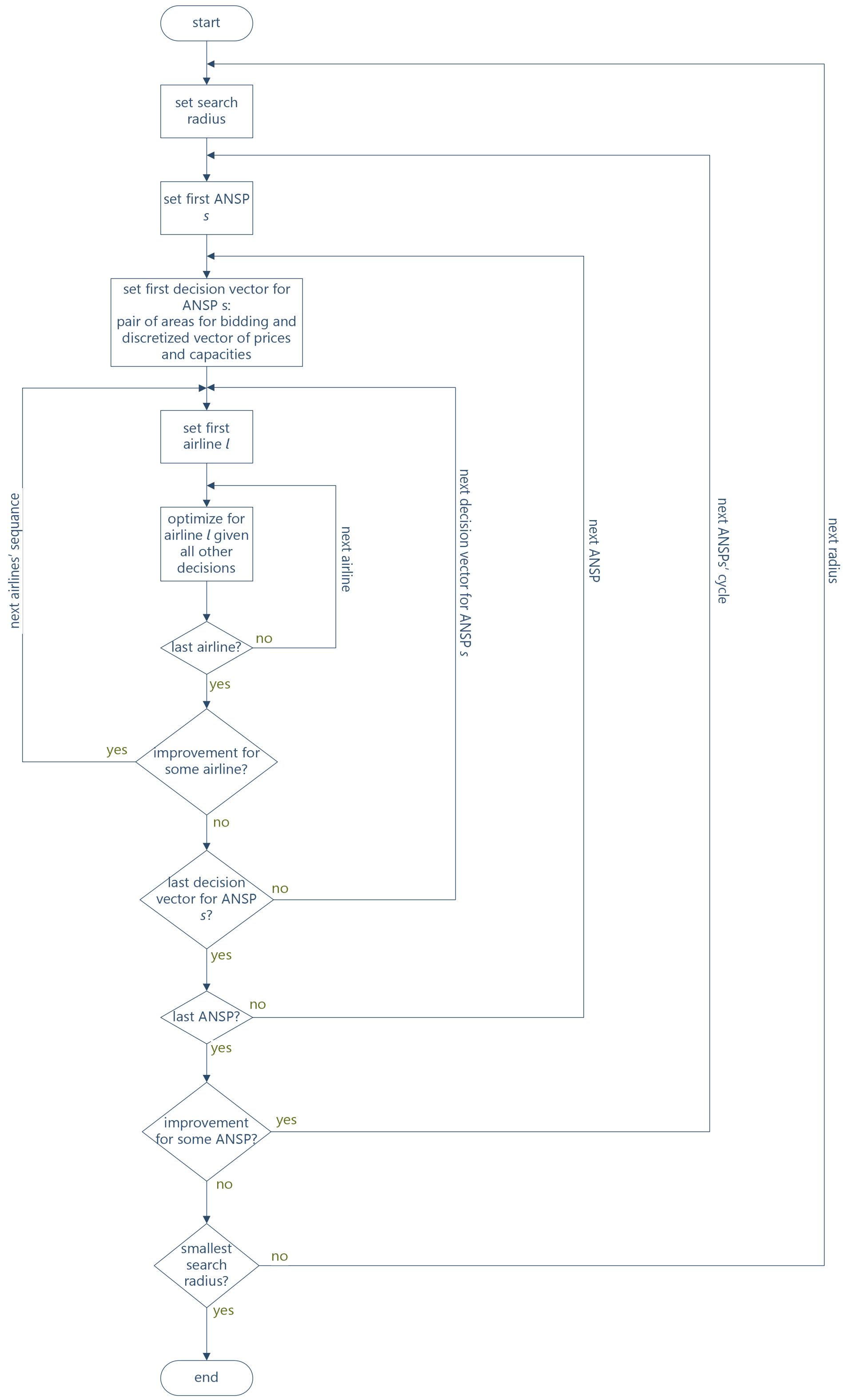


Figure 1: Solving the game for air traffic control companies & airlines

In order to analyse the potential impact of the introduction of auctioning air navigation services, we develop a case study that covers 50% of the European market. The network analysed is depicted in Figure 2 and includes six ANSPs, represented by the coloured arcs, six major airports, three regional airports and four additional nodes (yellow arrows) to aggregate flights to and from the region. 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.

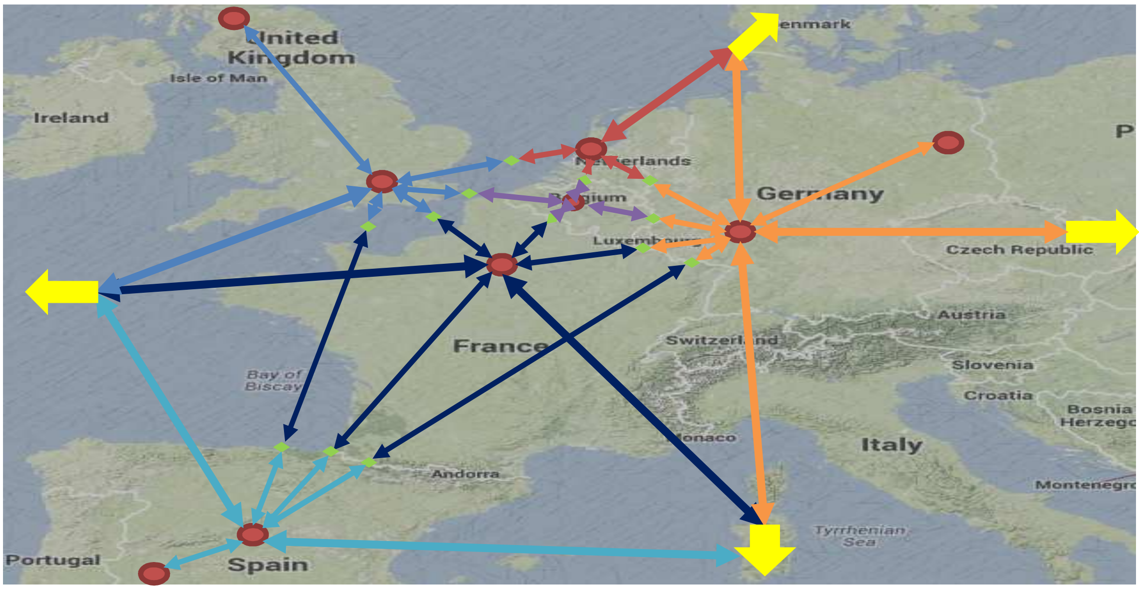


Figure 2: European air traffic control network case study

Based on the six country case study, we focus on six ANSPs and collected data on ENAIRE (Spain), Belgocontrol (Belgium), DFS (Germany), DSNA (France), LVNL (Netherlands) and NATS (UK). In 2014, according to the ATM Cost-Effectiveness 2016 Benchmarking Report (Eurocontrol, 2016a), 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. Out of the total European ATM system, 58% of the delay minutes were attributed to the ANSPs in 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.

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, British Airways-Iberia and Air France-KLM, the main European airlines in the three airlines alliances that exist today. For the purposes of this case, the low cost carrier group is represented by Easyjet and Emirates airline was chosen as the representative carrier for the non-aligned carrier group. 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.

In order to estimate potential equilibria outcomes in 2035 and 2050, we utilize the predicted instrumental flight rules en-route and terminal movements as published in the Eurocontrol Challenges of Growth (2013) reports. 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%. In the scenarios, we analyse the global growth and the fragmented world demand forecasts in order to test the widest range of potential solutions.

We estimate the behaviour of labour rent seeking ANSPs that are price capped and refer to this as the base-run. As shown in row 1 of Table 1, 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. The labour level decision variables are approximately equivalent to current staff levels and technology levels are also set at current levels. In the game developed, we assume a continuity of potential SESAR solutions such that a technology level of 1 indicates the current technology levels and a technology level of 2 indicates that all relevant parties have invested in the full SESAR1 technologies outlined in the 2012 ATM Masterplan. Investing in technology will increase the fixed costs and capacities offered by the ANSP and reduce the variable costs slightly. In turn, the technologies are expected to reduce congestion costs for the airlines which balances out the slightly higher operational costs caused by the investments. 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 costs per available seat kilometre similar to those reported in their financial statements. Consequently, the modelling approach suggests that we are able to reproduce the 2014 transport equilibria outcome.

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 row 2 of Table 1. 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 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. In row 3, we tested the potential outcome were non-profits to serve the market without an auction, as occurs today in Canada and Switzerland. The summarised results show that in four of the six countries, both the charges are set below current levels and 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. In row (4), 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 suggests 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. In summation, simply lowering the price cap to more stringent levels is unlikely to lead to investments in new technologies.

The outcome of the scenarios in which governments introduce a tender system and ANSPs are modelled as for-profit entities is presented in the bottom half of Table 1. As a result of the auction, three companies each win two tenders, thus serving two of the countries in the case study. In a few of the non-profit scenarios, four companies remain in the market. The for-profit result in row 5 suggests 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 continuity constraints) whereas in France, five potential bidders exist (with headquarters located in Spain, the UK, Germany, Belgium and France). We note that in this equilibrium, 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. 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 companies for this result to hold over time.

For planning purposes, we test demand sub-scenarios for the fragmenting world and global growth demand forecasts produced by Eurocontrol (2013a and b). Thus we span the potential outcome set from the two extreme cases in 2035 (rows 7 to 10) and 2050 (rows 11 to 14). The charge levels fluctuate as 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 with the growth in output and technology levels remain stable in the for-profit scenario.

With respect to the airlines, under the auction system with lower charge levels, all airlines are better off and the costs per available seat kilometre 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 Member 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).

We also investigated the possibility of defining ANSPs as non-profit entities, similar to the Canadian approach, but also participating in auctions. The equilibria outcome in row 6 leads to four companies winning auctions as compared to three in the for-profit scenarios. 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 1: 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:														
1	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
2	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
3	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)
4	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:														
5	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
6	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
7	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
8	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
9	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
10	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)
11	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
12	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)
13	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
14	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)

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) argues 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. The equilibria outcome shows similar levels of production but charges that return 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. The assumption here is that in the second round every incumbent will face at least one additional bidder. 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 new entrants. Alternatively, in the case of insufficient bids, the Member States could connect price bids to the values set in the previous auctions.

2.2 Agent-based simulation approach

Agent-based modelling offers a way to model socio-economic systems composed of agents that interact with and influence each other, learn from their experiences, and adapt their behaviours. The global behaviour emerges as a result of the interactions of many individual behaviours, showing patterns, structures, and behaviours that were not explicitly programmed into the model, but arise from the agent interactions. This section presents the agent-based models that have been developed in order to evaluate the outcome of two different institutional designs: (i) the tendering of licenses to operate en-route air traffic services in specific geographical areas and (ii) the provision of en-route air traffic services on a sector-less OD pair basis.

2.2.1 Tendering of licenses to operate en-route air traffic services in specific geographical areas

The model simulates the tendering of licenses to operate en-route air traffic services in specific geographical areas and for a certain period of time. It comprises three main elements:

1. Geographical context, which provides the environment for the agents to operate in.
2. Agents. Three types of agents, representing the main actors of the simulation, are considered: the regulator, the ANSPs and an airline.
3. Exogenous variables, which represent arbitrary external conditions that affect the model but are not affected by it. They include the fuel price and the passenger demand.

The simulation consists of two stages (see Figure 3): The first stage simulates the tendering process, in which ANSPs compete for the control of different geographical areas. In this stage, only the regulator and the ANSPs participate. ANSPs submit a certain unit rate per service unit per area that will be the maximum unit rate applicable in that area during the license period. Contract conditions in the tendering process include the minimal capacity the ANSPs have to provide during the license period and the maximum market share an ANSP can handle due to competition regulation, in order to avoid monopolistic behaviour. The second stage simulates how agents evolve between auctions. In this stage, an airline aims to meet total passenger demand and react to the ANSPs decisions by choosing different routes according to the air navigation charges applied by the ANSPs in each geographical zone. For the sake of simplicity, we are modelling a single airline agent whose goal is to meet the total demand, and no congestion costs are considered. Charges are adjusted every given period of time until the license period is over. Once the license period expires, the tendering process is repeated. This could lead to contract renewal for the incumbent provider or to a new provider supplying the market. Those ANSPs that do not get any area are assumed to go into bankruptcy and disappear from the market. The simulation is finished when the temporal horizon is reached.

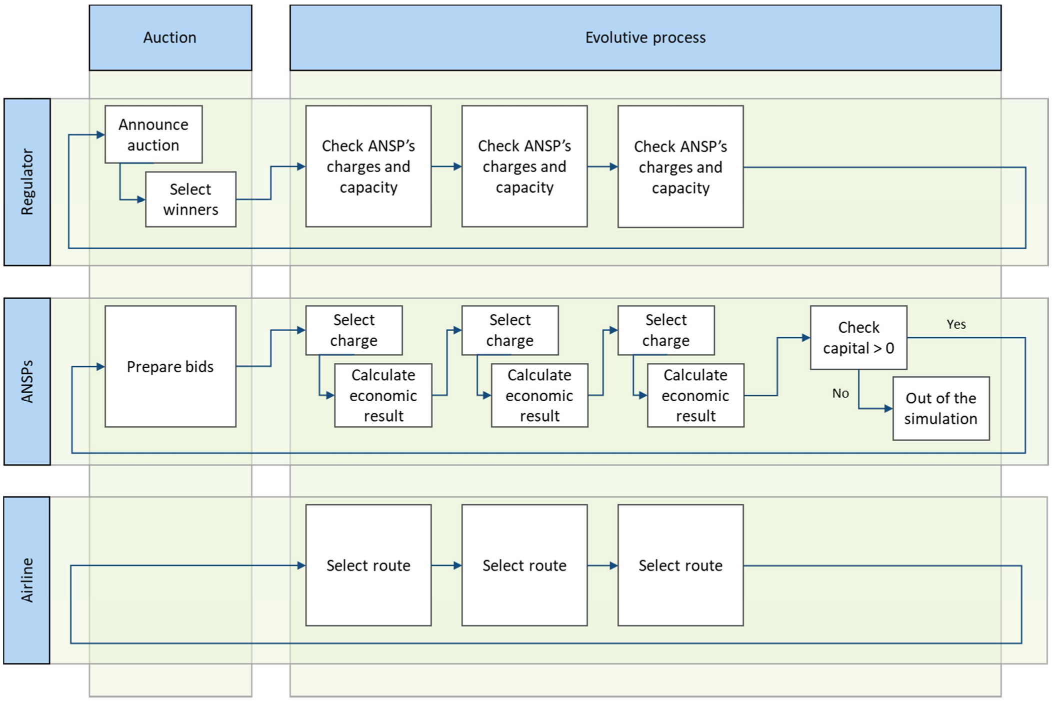


Figure 3: Simulation scheme

The ANSPs submit a bid corresponding to the maximum charge that would be applied to the auctioned zone as shown in Figure 4. ANSPs will be allowed to apply lower charges in order to influence demand (competition in the market), but not higher charges. To submit the bid the ANSPs take the following actions:

1. Calculate their total resulting market share in case of winning the auction and evaluate if this meets the condition of the maximum market share allowed.
2. Determine the minimum profitability they want to achieve. This lies between a minimum and a maximum value of the total cost of controlling the network, and it depends on an adaptive factor that takes into account the current status of the ANSPs.
3. Estimate in an iterative process the best bid charge by multiplying the current charge by a bid factor. The bid factor ranges from 0.5 to 1.5, in steps of 0.001 to limit the number of calculations. For each bid factor, they: (a) estimate the resources needed according to

their technology level and the expected number of flights, calculated based on the passenger demand forecast and the average plane size and load factor; (b) estimate the total expected profit, as the difference between the expected income and cost, and the profitability, dividing the expected profit by the expected cost; (c) obtain the probability of beating their competitors. This is calculated with one of the following learning methods: Friedman and Gates, which characterise the behaviour of all their competitors and estimate the probability of winning the auction accordingly, and Fine, which only characterises the pattern of the winning bids of previous auctions, (d) calculate the auction expected profit, defined as the product of the expected profit by the probability of winning the auction.

4. Submit the bid that maximises the auction expected profit

Once the regulator has allocated the areas to the winning ANSPs, they decide the amount of capital to invest during the following license period in order to upgrade their technology level. This amount corresponds to a percentage (set to 80% in the simulations described in this document) of the expected profit of the starting license period.

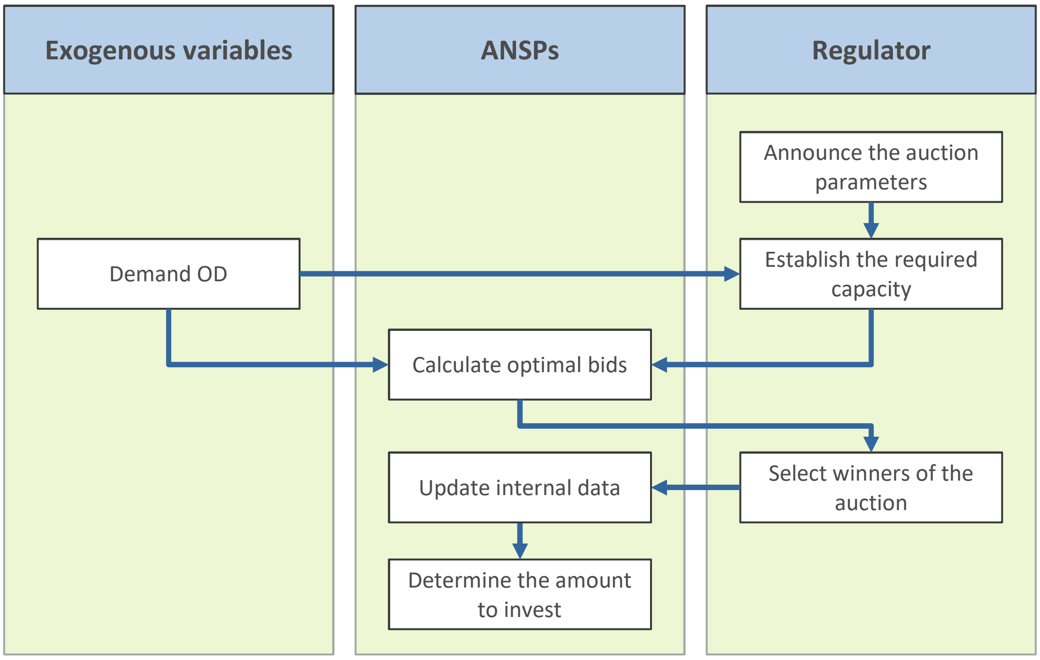


Figure 4: Scheme of agents' decisions in auctioning process

In the evolutive process all the three agents participate. The sequence of agents' decisions and actions follows the scheme included in Figure 5. The Regulator ensures that the ANSPs provide the required capacity and do not select a charge greater than the one they bid, and stores the public information that will be used by the ANSPs and the airline in future steps. Similarly to the auctioning process, each ANSP takes the following actions for different combination of charges within the areas it is controlling: (i) estimate the resources needed according to the demand forecast, the charge of their competitors and the distance that each routes flies over each charging zone; (ii) estimate the profit of the combination of areas they control during the following time step; (iii) select the combination of charges that maximises their expected profit; and (iv) after each season, once the airlines have selected the route of the flights, update their economic results. The airline's objective is to meet the passenger demand minimising their costs. To do so, once the ANSPs publish the charge in each charging zone and according to the total passenger demand (which is assumed not to be affected by the charges), the airline sets the number of flights per OD pair and selects the route of each flight according to a multinomial logit model in which the costs of flying each route are the input data. The reason for using a logit model instead of choosing the cheapest route directly is that the model does not capture some elements such as congestion or weather conditions which can lead airlines to choose routes different from the ones that minimise the cost of fuel and air navigation charges.

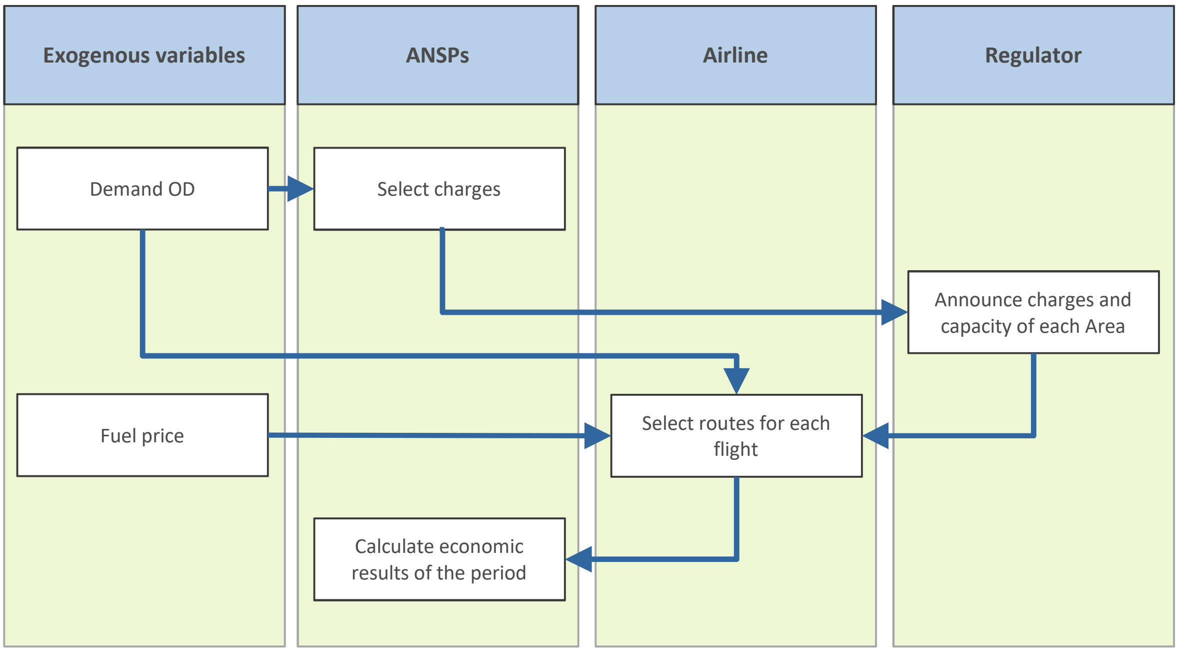


Figure 5: Scheme of agents' decisions in evolutive process

The proposed case study simulates the hypothetical outcome of the liberalisation of the ATM market in Western Europe (Figure 5) until 2050, if liberalised in 2015, according to different auctioning parameters.

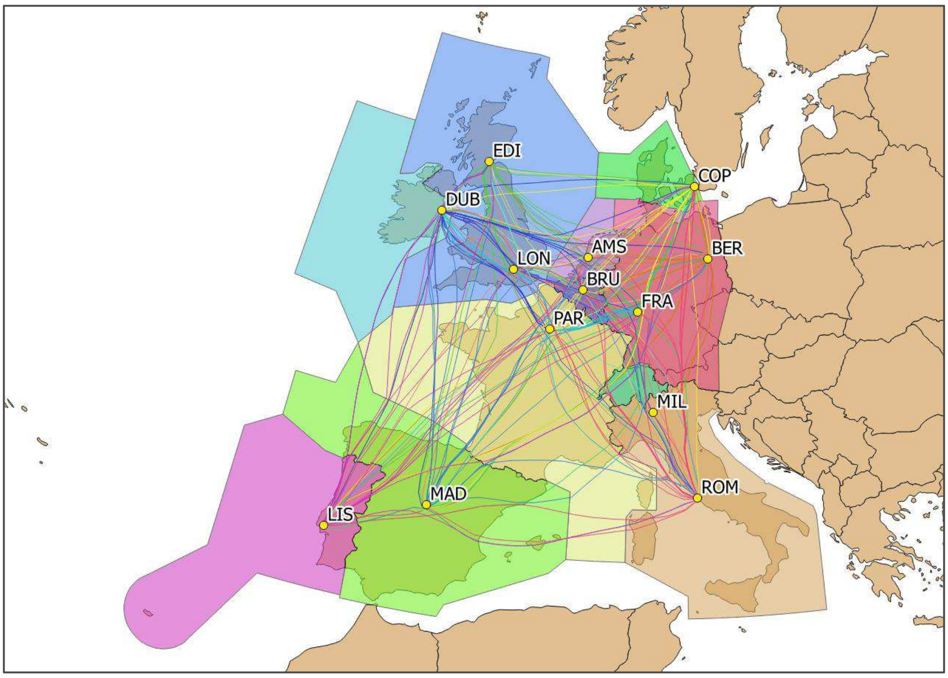


Figure 6: Geographical context

To analyse the outcome of different auction parameters, different scenarios have been built by modifying the main parameters of the auctioning process:

- the maximum allowed market share: 30, 40 or 60%
- the auctioning order: auctioning the areas in different orders, according to the market share of the countries: ascending, descending and mixed order. When the order is set to mixed, first the zone with the lowest market share will be auctioned, followed by the zone with the greatest market share, then the zone with the second lowest market share, and so on
- the duration of the licenses: 5 or 10 years

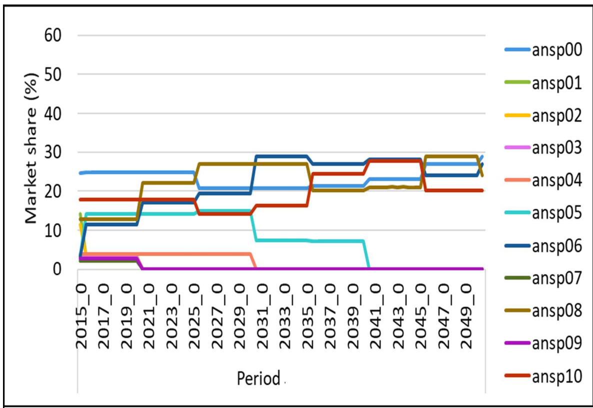
According to the results for all tested scenarios, which are represented in Figure 7, Figure 8 and Figure 9, we find that the ANSPs which control the biggest charging zones at the beginning of the simulation (i.e., the ANSPs with the highest market share in the first period) perform better in the long term, since they have more resources to invest at the beginning of the simulation, which results in faster technology adoption. On the contrary, the smallest ANSPs usually disappear between the second and the fifth auction as they are not competitive enough against the dominant ANSPs, due to the economies of scale of these dominant ANSPs.

When there is a dominant ANSP controlling most of the market, thanks to its investment capacity and the economies of scale due to the possibility of reallocating ATCOs to different charging zones according to the labour requirements, both the total number of ATCOs and the average charge are lower than in the case where the market is controlled by more ANSPs. However, what seems a clear benefit in the short/medium-term, may lead to the emergence of an oligopoly in the long-term.

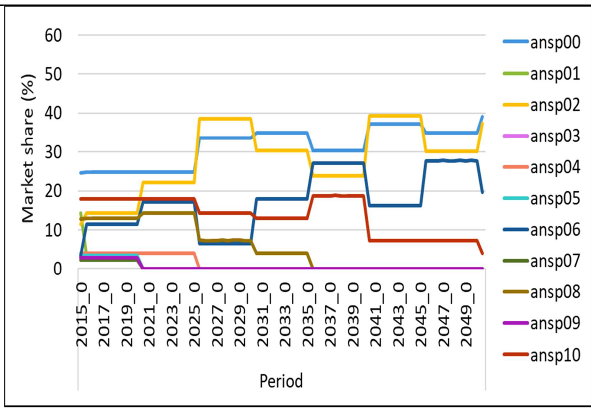
We find that:

- If the maximum market share is set to 30%, the competition between ANSPs increases as the total market is divided into a larger number of ANSPs. However, this could be too restrictive as the market share of France is already more than the 20% of the case study. Also, in the 30%-scenario, the ANSPs have less economic capacity to invest in the adoption of technology as in the other cases. Hence, we do not see lower charges as a consequence of more competition.
- When the maximum market share is set to 60%, the lowest charges are obtained, mainly due to economies of scale. However, two main ANSPs control more than the 90% of the market, which could lead to a duopoly in the future.
- With a market share of 40% there is a significant level of competition (at least 4 ANSPs are competing in the analysed scenarios) and ANSPs have the economic capacity to invest on the adoption of technology.
- The auctioning order has an important effect on the tendering results, obtaining better bids for the countries that are first auctioned.
- There is a considerable difference in the resulting market share of the ANSPs depending on the license duration. In the 10-year scenario the outcome suggests that the market share of ANSPs remains more stable while in the 5-year scenario, the ownership of the charging zones switches after every tendering process. Thus, it can be concluded that a license duration of 10 years leads to more homogeneous ANSPs and more stable market with more ANSPs, but not necessarily to a more competitive market.

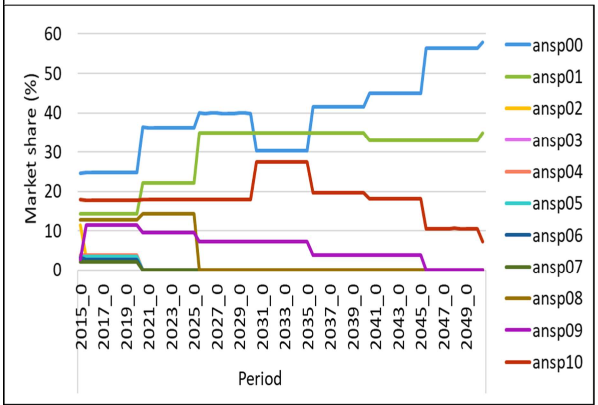
This suggests that the optimal performance of the tender is obtained with a maximum market share of 40% and auctioning the countries in a mixed order.



Max. market share: 30%



Max. market share: 40%



Max. market share: 60%

Figure 7: Resulting ANSPs' market share for different values of the maximum market share. (Auctioning order set to "mixed" and licenses duration to 5 years)

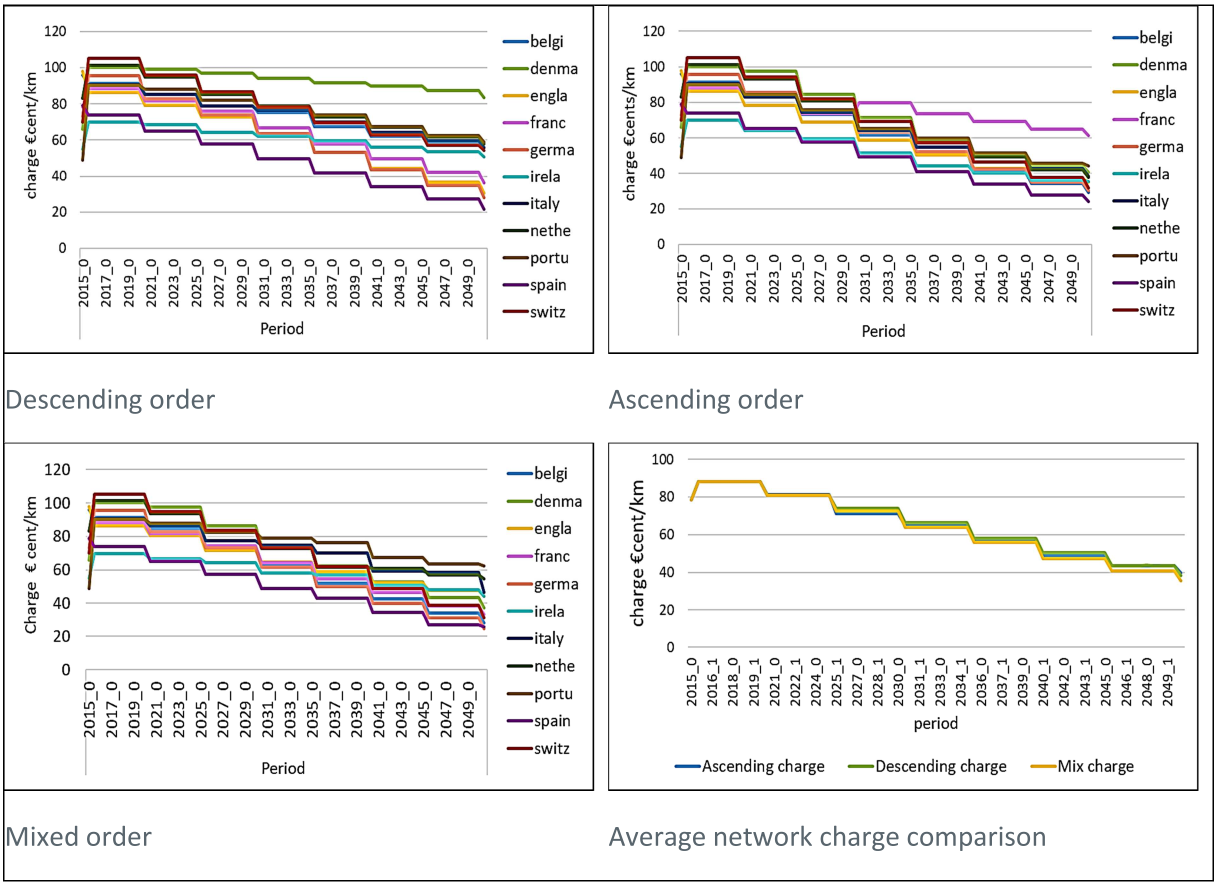
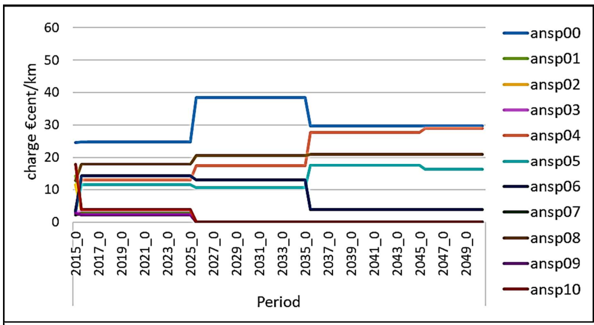
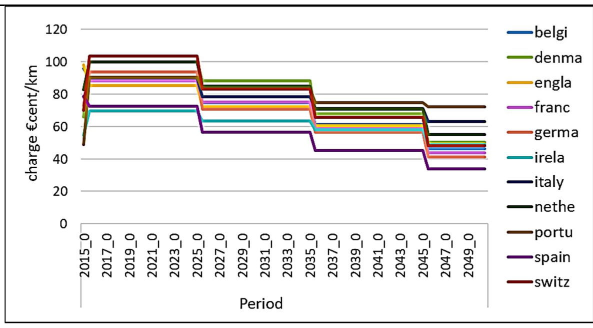


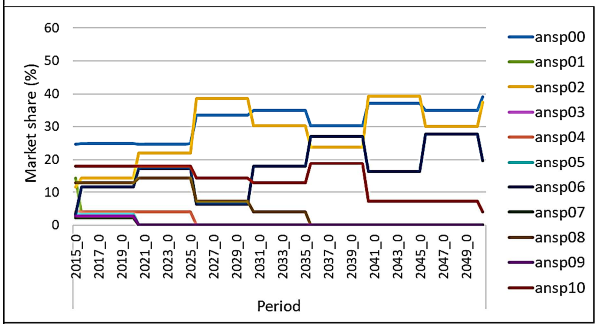
Figure 8: Resulting national charges for different auctioning orders. (Maximum market share set to 40% and licenses duration to 5 years)



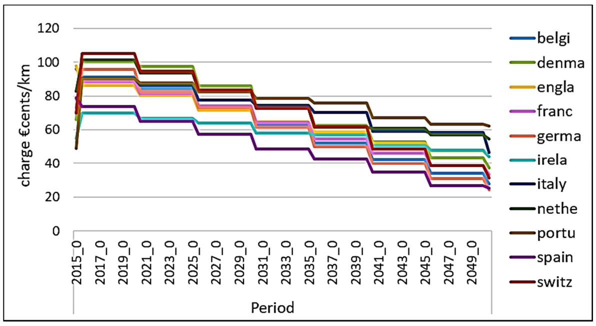
ANSPs' market share (licenses: 10 years)



National charges (licenses: 10 years)



ANSPs' market share (licenses: 5 years)



National charges (licenses: 5 years)

Figure 9: Resulting national charges and ANSPs' market share for different durations of the licenses. (Maximum market share set to 40% and auctioning order to "mixed")

2.2.2 Provision of en-route air traffic services on a sector-less OD pair basis

This model simulates a futuristic sector-less scenario in which ANSPs provide air navigation services to flights from origin to destination. As opposed to the mechanism described in section 2.2.1, where there was mainly competition for the market (with only limited competition in the market), in this institutional design there is full competition in the market. In this model, ATCOs can work at any OD pair and ANSPs can provide air navigation services in all European regions, described in Figure 7. Hence, there is no preference to work on specific routes. The objective of the ANSPs is to maximise their profit. Different options were considered to simulate this futuristic scenario, such as, for example, tendering the OD pairs to a group of ANSPs (competition for the market) which will then compete in the market of the specific OD or letting the airlines select an ANSP which will monitor their whole network. Finally, to explore this idea in a simple manner, we decided to simulate a market design similar to the electricity market (see Figure 10), in which airlines submit their bids and

ANSPs simultaneously submit their ask prices of controlled flight-kilometres to the Regulator, which chooses some price *p* that clears the market (see Figure 11). In this model, ANSPs have the incentive to invest in improving their efficiency and reduce their costs, otherwise their productivity relative to competitors will decrease and they may be out of the market.

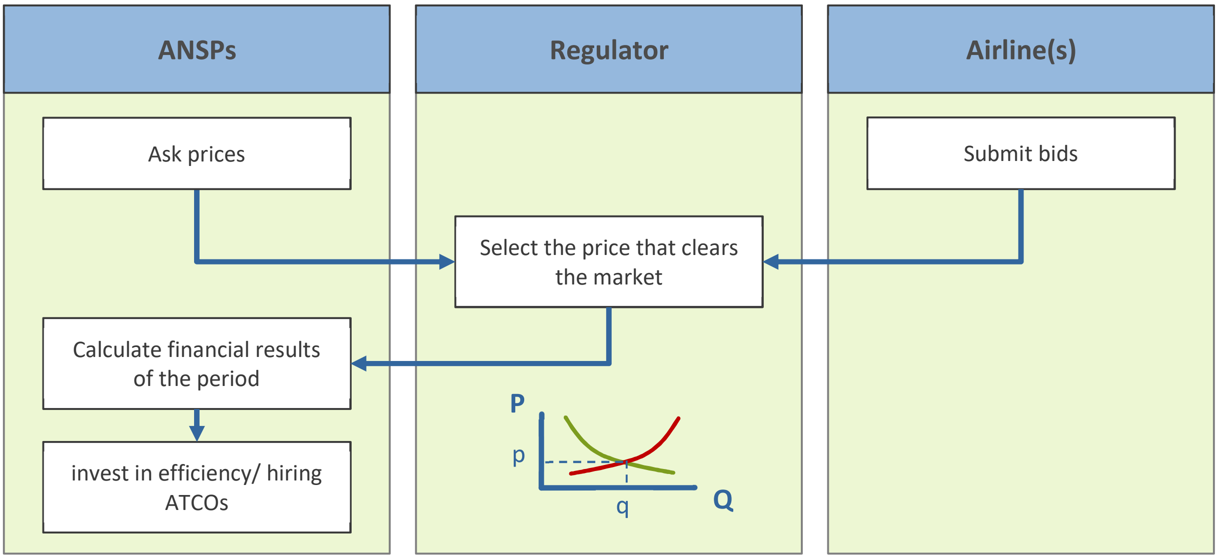


Figure 10: Scheme of agents' decisions

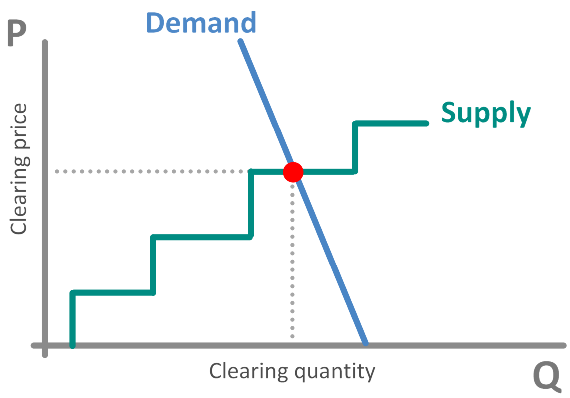


Figure 11. Clearing price and clearing quantity estimation

The ANSPs will submit their true value since bidding the true value is a dominant strategy in this type of auction (uniform price), as in Vickrey auctions. That is, the best choice of the bid is exactly the cost of the ANSP.

To explain this strategy, let's assume v_i is the bidder i's true value for the good and b_i is the amount bid. Then the payoff of bidder i will be 0 if b_i is not the winning bid, otherwise the payoff will be equal to v_i - b_j, being b_j the market clearing price.

In this strategy behaviour, there are two cases to consider: $b_i > v_i$ and $b_i < v_i$. In both cases, the key point is that the value b_i only affects whether the bidder i wins or not the auction, but it does not affect how much i will get paid, which will be determined by the market clearing price.

- $b_i < v_i$. In this case, it only affects if bidder i would win with b_i but would lose with v_i. Then the highest other bid, b_k, must be between b_i and v_i, so bidder i would have a negative payoff ($b_k – v_i$).

- $b_i > v_i$. In this case, it only affects if bidder i would lose with b_i but would win with v_i. Then the highest other bid, b_k, must be between b_i and v_i, so bidder i would have non-profit, whereas he could have had a positive payoff ($b_k – v_i$) if bidding his own true value.

These arguments explain why truthful bidding is the optimal strategy regardless of what other ANSPs do. By bidding their true values, ANSPs ensure that the probability of winning the auction is higher than by bidding more than their true value and, if winning, they would get a positive payoff or, at least, they will not lose money (if bidding just the market clearing price).

The proposed case of study simulates a hypothetical ATM market in Western Europe in which en-route air traffic services are provided on a sector-less OD pair (Figure 12).

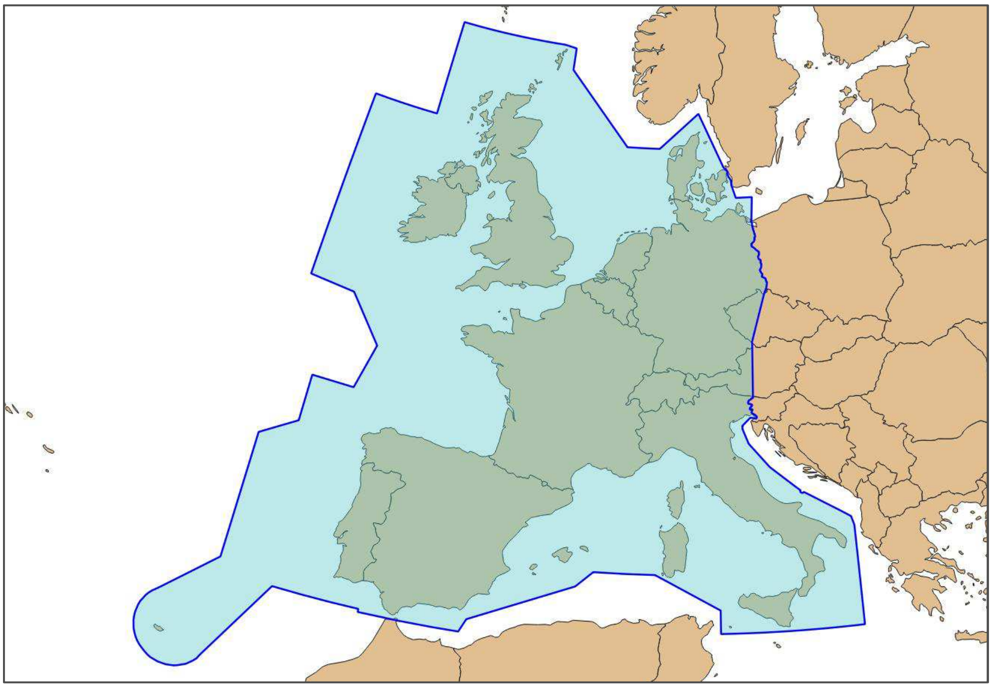


Figure 12: Geographical context

The objective of the model is to analyse the outcome of different ANSPs' and auction's parameters such as the initial productivity and size of the ANSPs and the maximum market share. To this end we have modelled several scenarios by modifying these parameters.

To analyse the impact of different ANSPs' parameters, we have run a simulation in which ten theoretical ANSPs participate and the maximum allowed market share is set to 40%. To evaluate the trade-off between the size of the ANSPs and its productivity, all of them have a different number of ATCOs and different values of productivity which represents the flight-hours an ATCO can monitor in one hour. The higher its productivity, the lower the number of ATCOs. The model suggests that the most important parameter of ANSPs is their productivity, as the most productive ANSPs perform better during the simulation regardless of their size. This is due to their ability of bidding lower charges, which ensures them some profit in every time step.

According to the results obtained during the simulation, due to their ability of bidding lower charges which ensures them some profit in every time step, the ANSPs whose initial productivity is higher at the beginning of the simulation perform better. The market share of each ANSP during the simulation is depicted in Figure 13a. It clearly shows that the most efficient ANSPs increase their market share progressively and the less efficient ones disappear from the market (market share equals to zero) until a stable situation is reached by 2040. Figure 13b represents the evolution of the productivity of ANSPs and indicates that by 2050 the three dominant ANSPs achieve the maximum productivity. As ANSP07 is the less efficient ANSP at the end of the simulation, its bid is higher than their competitors, which means that its bid price is equal to the market clearing price. Hence, it does not obtain any profit to invest and upgrade its technology level.

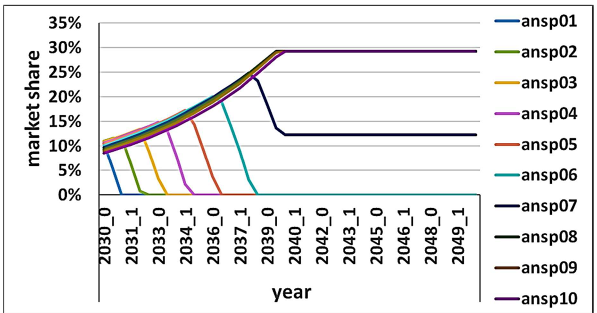


Figure 13a: ANSPs market share

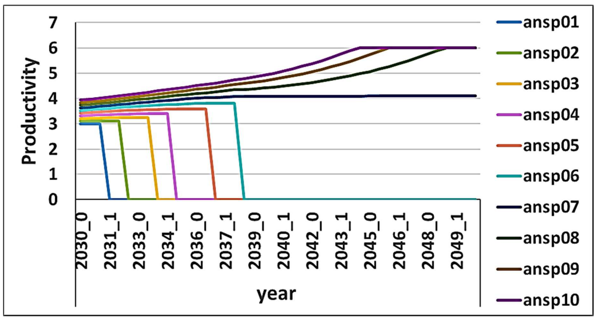


Figure 13b: ANSPs productivity

Regarding the maximum market share allowed, the model shows that the market is always consolidated by the minimum number of ANSPs possible. Hence, a maximum market share is needed in this type of market to avoid a monopoly/oligopoly situation.

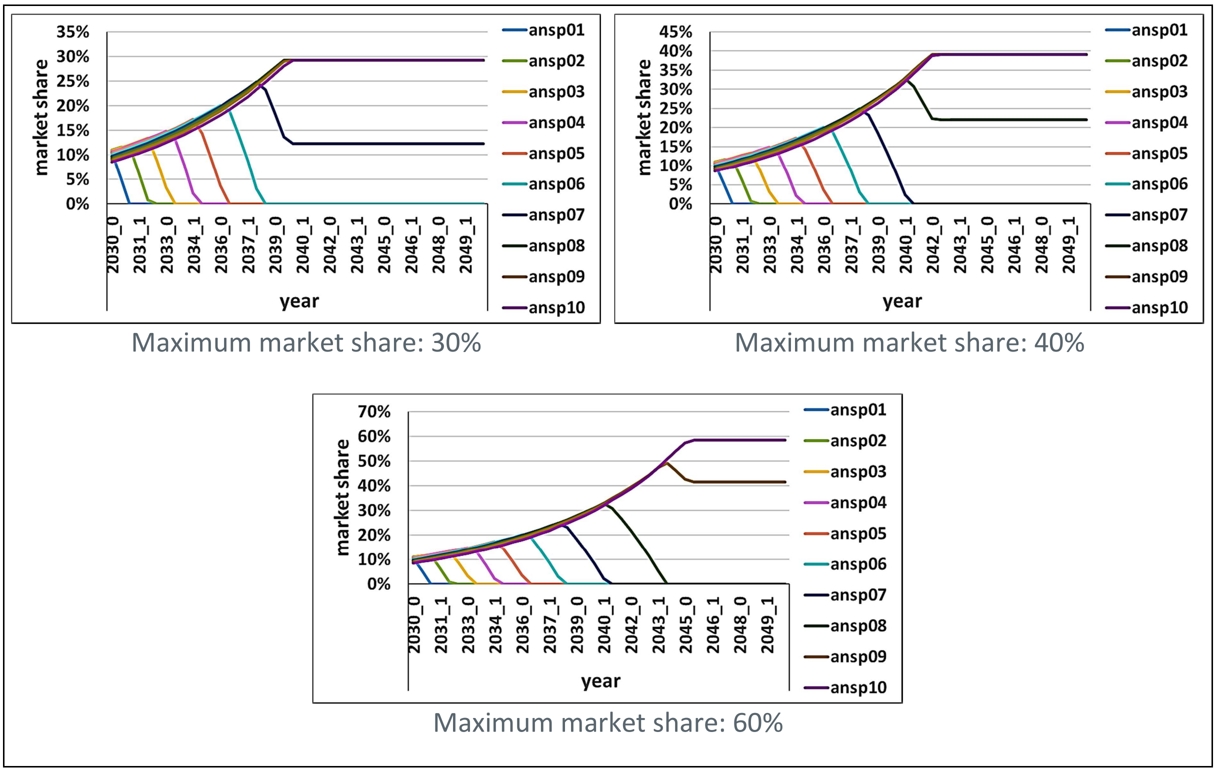


Figure 14: ANSPs' market share for different values of the maximum market share allowed

A noticeable output of this model regarding the prices is that, once the market remains stable, that is, the market share of ANSPs does not vary, the network charge remains constant (Figure 14). This is due to the fact that the least efficient ANSP set the market clearing price such that it does not get any profit to invest in upgrading its efficiency. Hence, this ANSP cannot offer lower bid charges in the following auctioning processes and the network charge remains constant.

3 Conclusions

According to FlightPath 2050 goals, passengers are expected to be in a position to make informed choices, arrive within 4 hrs door-to-door anywhere in Europe, that the flight ETA will be reduced to 1 min and that the transport services will be interconnected and seamless. Furthermore, the air traffic management system is expected to serve 25 million flights. Based on the results of the modelling approaches in the COMPAIR project, it would appear that further commercialization and the creation of a competitive environment would contribute to achieving these goals.

Introducing an auction system for air traffic control provision at the level of each European State would be one means of creating competition for the market. A continuous 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.

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 occur 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 current price caps. Based on the results of the multiple analyses, 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 lays 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, mainly by the larger companies, and charges would be lower than the current price caps but 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.

According to the agent-based simulation, the most important parameter influencing the outcome of the tendering, both with respect to charges and to the market share of the ANSPs, is the maximum market share permitted across the European skies. A high, maximum, market share favours the existence of relatively large ANSPs which draw greater benefits from economies of scale, but could lead to a duopoly in the longer term. The order in which the countries auction their services also has a strong impact on the local charges of each country, although the global network effect is not as important as the average network charge is the same in all the tested scenarios. Finally, the duration of licenses shows different outcomes but there is no clear evidence to assert which one would lead to better results. The shorter auction period, for example five years, leads to lower efficiency gains as compared to a ten-year process, but higher levels of competition in the longer term.

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 that may be of interest would be 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.

In summation, returning to the questions posed at the beginning of Section 2, we find the following:

1. *What should the rules of such an auction be?*

An auction every five to ten years, depending on the preference of the Member State for efficiency versus stability, ought to set minimum levels of service required by the State from the air traffic control company. This service level is required in order to ensure sufficient capacity is being produced by the geographical monopolist over the timeframe of the service. Furthermore, the Member State may choose to permit the company to adapt the charges as a function of improved service levels thus encouraging investments in technologies.

2. *Would the goals of the Single European Skies initiative be achieved?*

Under a tendering process over time, defragmentation should be achieved as companies win more than one Member State auction. Serving larger airspaces will provide cost advantages and encourage investment in technologies. Auction process also leads to competitive bidding such that some of the cost efficiencies and economies of scale will be passed on to the airlines in lower charges. Savings could reach 50% of current revenue turnover depending on the number of bidders competing and the activity level of a specific airspace.

3. *Would an auctioning system continue to achieve the goals over time?*

Both modelling approaches suggest that the auctioning process should continue into the future provided the EU sets a maximum level of activity per company. In other words, if no company is permitted to serve more than 20% of the overall air traffic movements across Europe, five air traffic companies will continue to serve the area and ensure sufficient bidding into the future. Whilst a single company could clearly serve the entire airspace efficiently, as occurs in the United States today, it is less likely that the airlines would benefit in the longer term and this would then impact the passengers in the longer term.

4. *Is there a preferable ownership form of air traffic control companies?*

It appears to be clear that private companies would lead to the most defragmentation of the system and the greatest efficiencies, both in terms of the costs and the likelihood of adopting new technologies. A non-profit system, as in Canada, would create improvements with respect to the current system, but not to the same extent as private companies with a tender process.

5. *With entirely new sector-less technologies, how would the market develop?*

In the proposed market design, the model suggests that charges would be reduced rapidly until a stable situation is reached producing large benefits in the transition period. Once the stable situation is reached, the whole market would be dominated by the minimum possible number of companies. Hence, a maximum market share shall be established by a competition regulation in order to avoid the existence of oligopolistic behaviours.

4 References

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