Cost savings from trajectory deviations in the European air space

Abstract

Air transport deregulation has lead to an increase of air traffic, together with a reduction of air fares. Air fare reduction has narrowed operational margins of airlines, bringing financial and employment instability. This has brought airlines to pay increasing attention to flying costs reduction. Two important components of flying costs airlines can try to cut modifying the planned flight are en route charges and operational costs. We rely on Demand Data Repository (DDR2) data to calculate deviations from planned flight trajectories to analyse the extent to what airlines try to cut operational costs making shorter flights than planned if possible, and cut en route charges providing a planned flight with lower en route charges than the planned flight. Our findings show that there is no generalised strategy among airlines to reduce en-route charges asking for deviations of the planned route. On the other hand, airlines are achieving savings of operational costs regularly. Higher savings per nautical mile are obtained in night flights, with longer planned distance and operated by low cost carriers.

Introduction

The importance of air traffic analysis is becoming increasingly important, as air transport is one of the sectors that are constantly growing: according to Bourguignon and Darpeix (2016), currently, 'traffic grows twice as fast as GDP'. This growth can be attributed to the deregulation of air transport in the most relevant air transport markets, included the European, since the 1980s. This deregulation lead to an increase of air traffic, together with a reduction of air fares (Alderighi et al, 2012). Air fare reduction has narrowed operational margins of airlines, bringing financial and employment instability (Goetz and Vowles, 2009). This has brought airlines to pay increasing attention to cost reduction (Zuidgberg, 2004). Two important components of flying costs airlines can cut modifying the planned flight are en route charges and operational costs.

While operational costs can be approximated by the total distance flown, the calculation of en route charges is more complex. In the European airspace, en route charges are collected by EUROCONTROL on behalf of its member states through the Central Route Charges Office (CRCO). The invoicing process for these charges is described in CRCO (2019). Charges for each en route charging zone (ECZ) are proportional to a distance factor, proportional to the distance between entry and exit points of each ECZ. The distance factor is calculated with information stated in the planned flight plan reported by the airline before the flight takes place.

Airlines may have incentives to behave opportunistically: once the flight is started, pilots would request route modification that would diminish operational costs by crossing areas with higher en route charges. These route modifications are the result of an *in situ* interaction between pilots and air traffic controllers, depending on the circumstances of real air traffic. Operational costs can be considered a function of the total distance covered, so a deviation from the planned flight resulting in a shorter route results in a reduction of operational costs. Acting this way, airlines could not only lower their operational cost, but also en route charges, reporting a planned route that passes through areas with cheaper en route charges. In spite of the rich available information on air trajectory deviations, to our knowledge no studies exist examining the impact of these trajectory deviations on flight costs. We intend to fill this gap in the literature examining if airlines have a systematic strategy of reduction of flying costs through trajectory deviations. To achieve that aim, we analyse the impact of ex post route modifications on operational costs, possibly with routes that if planned would have led to higher en route charges.

Air trajectories and air trajectories deviation analysis

The trajectory of an aircraft specifies the position that the aircraft is taking at each moment in time during a flight. Definition of aircraft trajectories is an important area of air traffic management research. For instance, Dalmau and Prats (2015) and Dalmau et al. (2018) have defined an aircraft trajectory prediction and optimization framework defining continuous climb operations. Another example of trajectory research is Patron et al. (2013): they define genetic algorithms that define trajectories that reduce costs taking advantage advantage of tail winds.

As the trajectory determines the total distance flown, and the entry and exit points in each ECZ, it is also a key determinant of en route charges and operational costs. En route charges are a compensation for air traffic management (ATM) services carried out by each air navigation service provider (ANSP), but they also can be considered as a mechanism to provide the adequate incentives to airlines to enhance the effectiveness of the air navigation system (Castelli et al., 2004). An adequate selection of price levels of en route charges may lead airlines to schedule flights in less occupied slots, reducing congestion in air space (Deschinkel et al., 2002, Castelli et al., 2015). On the other hand, when defining flight trajectories airlines incorporate the fact that each ECZ has different en route charges costs (Ferencová et al., 2019), making them sometimes select longer routes with the aim of minimizing total costs (Delgado, 2015). All the efforts of optimizing aircraft trajectory before flying contribute to build the flight plan, defined before flight takes place.

Once the flight has started, there is the possibility of modifying the trajectory. Differences between the planned and real trajectories are air trajectory deviations. They are the result of interaction between pilots and air traffic controllers (ATCs). The mission of ATCs is twofold: they have to avoid safety problems and to make aircraft's trajectories conflict-free, but also, whenever possible, they can issue directs that shorten trajectories (so as to reduce fuel consumption) or that can improve the predictability of the system (EUROCONTROL, 2019). So, the real flight trajectory is the result of the interaction between pilots and ATCs, and the real trajectory can be significantly different from the planned one.

The systematic study of differences between planned and real trajectories can give insights about the result of pilots and ATCs interaction, and its impact on air traffic management performance. Vitali et al. (2012) analysed statistical regularities in the air transport network, among which trajectory deviations. They found that most of the deviations occur at the end of the trajectory, being small modifications related with landing operations. Bongiorno et al. (2015) and Bongiorno et al. (2017) relied on DDR2 data to examine air trajectory deviations of European commercial flights of duration longer than ten minutes. We can consider these deviations as significant, different from the small route modifications pointed out by Vitali et al. (2012). The conclusions of their research give a relevant insight of the traits of significant air trajectory deviations (Bongiorno et al., 2017):

- Deviations occur more frequently far from destination airports.
- Deviations happen more frequently during night and during other low-traffic phases of flight. Since traffic is lower during night, deviations are not a need of dealing with safety problems, but rather the result of the possibility of issuing directs that will shorten the trajectory of flights.
- Deviations take place preferentially for angle-to-destination between 20 and 25 degrees.
- Performed routes tend to have a higher efficiency in contrast with planned routes.

These results show that most significant trajectory deviations attempt to increase route efficiency, rather than being caused with safety concerns, such as conflicting trajectories. The two studies analysing air trajectory deviations are contributions to analysis of statistical regularities of air transport networks. In this study, we will use trajectory deviation analysis to examine airline's behaviour regarding cost reduction.

Computation of route charges and operational costs

The Central Route Charge Office (CRCO) is the EUROCONTROL central office that collects en route charges on behalf of its member states. These charges help to fund air navigation and air traffic management facilities and developments (CRCO, 2019). CRCO also collects terminal charges, and air navigation and communication charges in the Shanwick Oceanic Control Area. Each Aircraft Operator (AO) receives a monthly bill in euro, independently of the amount of the En-Route Charging Zones (ECZ) it has overflown. This bill contains the summation of charges for each flight performed by the AO in that month. The participants of the en route charges system operated by CRCO are presented in Figure 1.

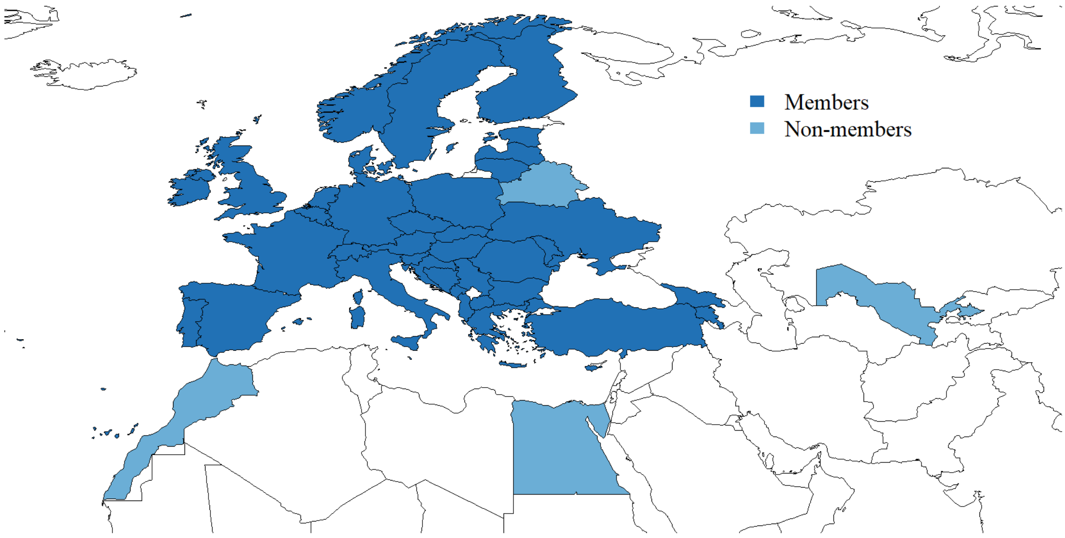

Figure 1 – Participants in the En-Route Charges System (ECS) that are member or not of EUROCONTROL

The en route charge (EC) of a flight is calculated by the following formula, where the summation takes place along the ECZ the flight has crossed:

$$EC = AWF \sum_{i=1}^{n} DF_i \, URC_i$$

In general terms and according to CRCO (2019), these three factors are defined as follows:

- AWF (Aircraft Weight Factor): the square root rounded to the second decimal of the Maximum Take-Off Weight (MTOW) (in metric tonnes, to one decimal) divided by 50.
- DF (Distance Factor for the i-th ECZ): the orthodromic distance between the entry and exit points of an ECZ expressed in km, divided by 100 and described in the last filed flight plan. For each take-off and each landing 20km are deducted, if there is a unique ECZ, the intersection points are substituted by the aerodromes of arrival and departure.
- URC (Unit Rate of Charge for the i-th ECZ): the charge in euro applied by a charging zone to a flight operated by an aircraft of 50 metric tonnes (weight factor of 1.00) and for a distance factor of 1.00'. From 2019, this metric has changed slightly by adding an administrative unit rate to URC, which has resulted in a Global Unit Rate (GUR). The values of GUR for the ECZ in charge by CRCO are presented in Figure 2.

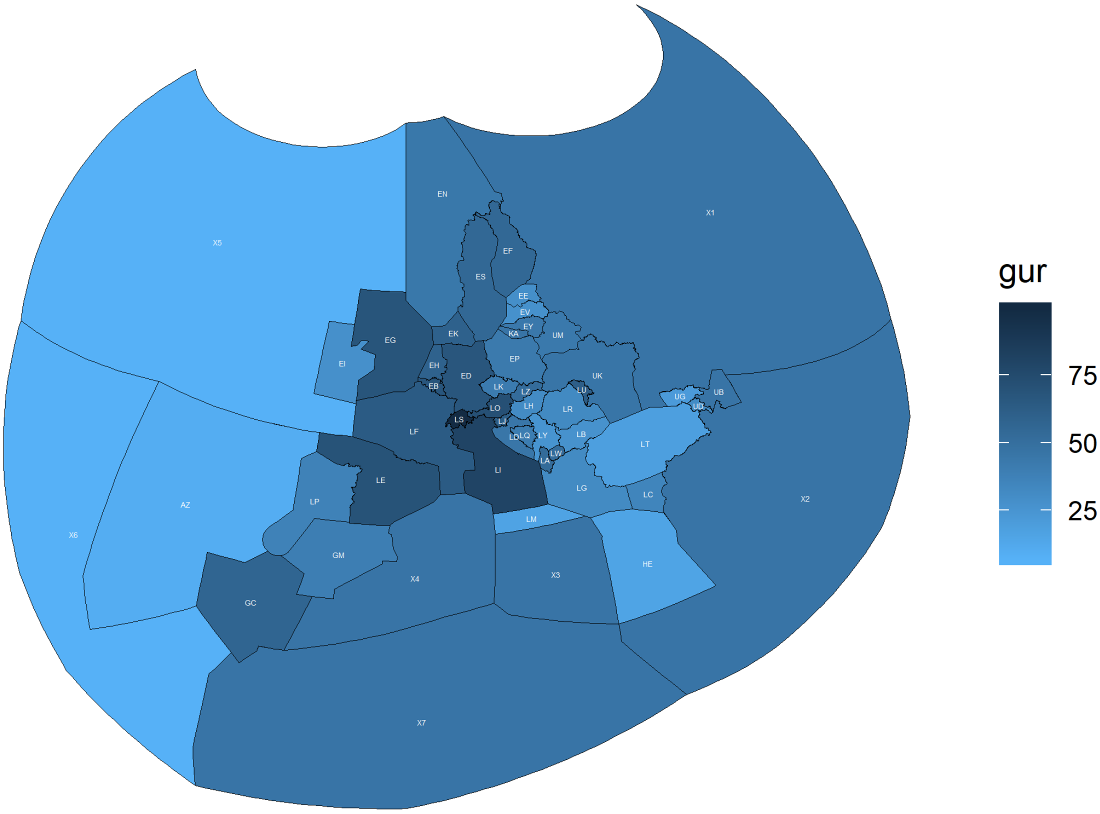

Figure 2 – En-route Charging Zones (ECZ) coloured by its URC (current GUR).

According to the EC formula, and preliminary calculations, several facts can be asserted:

- Distance and MTOW are directly proportional to EC with an order of magnitude close to 10^0.
- URC depends on the will of the state associated with the ECZ and has an order of magnitude close to 10^1.

Therefore, URC is the most influential factor and is also arbitrary and totally independent of the operation of an aircraft.

The other component of flying costs affected by flight trajectories is operational cost (OC), the cost linked of performance of flying different from en route charges. That cost is proportional to distance flown. OC have been assumed to be equal to 7.5 €/NM in accordance with the criterion used by EUROCONTROL's System for traffic Assignment and Analysis at a Macroscopic level (SAAM) when calculating the cheapest route (EUROCONTROL, 2018). SAAM calculates OC computing planned flight distance and EC using the CRCO's formula described above, and sums both results to obtain a Global Flying Operation Cost (GFOC).

Aircraft operators can save operation costs from trajectory deviations when:

- The aircraft deviates its trajectory over ECZ more expensive than the ones reported in the planned trajectory, and therefore used to calculate en route charges. As a result, the aircraft operator obtains a saving of en route charges (EC).
- The aircraft deviates its trajectory to cover a total distance shorter than the planned flight, resulting in a saving of operational costs.

Although the historical tendency is the decrease of OCs (Ashford *et al.*, 2011), they possess a more considerable weight in comparison to the ECs, as it will be shown posteriorly and as it can be understood intuitively. Ergo, it can be advanced that if EC is not large enough in relation to OC, the strategy to minimise EC will not be probably the best choice, unless this minimisation also leaded to a simultaneous optimisation of the sum of OC and EC.

Methodology

To evaluate the potential savings of global flying operation costs obtained from trajectory deviations, we have retrieved from the Demand Data Repository of EUROCONTROL (DDR2, https://ext.eurocontrol.int/ddr/home) information of planned flights (m1 files) and performed flights (m3 files) from December 2018 We have excluded the following categories of flights from the sample:

- Military and general aviation flights, as we are focused on costs of commercial flights.
- Flights crossing navigation points outside charging zones.
- Circular flights.
- Re-routed flights, which land in an airport different from the planned flight.

Once excluded these flights, we have retained 579,243 flights in our analysis. To compute total distance of performed flights, we have excluded navigation points with names starting with any of the following symbols: $, %, #, !. These are technical points that refine the route followed by flights but do not change the trajectory substantially. To compute total distance, we have relied on horizontal flight deviations (Vitali,2012), as they are more significant in terms of distance flown than vertical deviations.

To compute en route charges, we have also retrieved information about aircraft weights (.mwc files) and geometrical definitions of ECZs (.are files) and URCs (.ur files). Since polygons defined by *.are* files contained several imprecisions, it has been necessary to subject polygons related to December 2018 to a fixing process. This has enabled the optimisation of EC calculations.

To process the information of these files, we have computed en route charges and operational costs for each flight, to aggregate the results by relevant categories and to visualise and analyse results. This computation allows us to take advantage of available information from EUROCONTROL about aircraft routing to evaluate efficiently differences between flight costs on real and planned flights.

To examine the economic impact of flight deviations, we have defined the following metrics:

- DOC is the difference between planned OC (OC_1) and performed OC (OC_3). DOC being positive means that the flight has achieved savings in terms of operational costs.
- DEC is the difference between performed EC (EC_3) and planned EC (EC_1). DEC being positive means that the flight has achieved savings in terms of en-route charges.
- TS (Total Savings) is the summation of DOC and DEC and represents the savings achieved for a flight. A positive value of TS means positive savings during the flight.
- sDOC is the specific DOC. It is defined as the average DOC within a certain group of flights that share a particular characteristic.
- sDEC is the specific DEC. It is defined as the average DEC within a certain group of flights that share a particular characteristic.
- sTS is the specific TS. It is defined as the average TS within a certain group of flights that share a particular characteristic.
- dsTS is the specific TS per nautical mile. It is defined as the average TS per nautical mile within a certain group of flights that share a particular characteristic. It has been studied uniquely by airlines.

Results and discussion

Table 1 shows some generic results for the whole sample of flights. DEC are supposing insignificant losses for airlines (0,3% of EC1) and that DOC are supposing slight savings per flight (1,4% of OC1), which cumulated represent important figures for airlines.

Table 1-Selection of metrics for the whole sample

Metric	Value	Metrics	Value
Average OC1	5.549,43 €	Flights DOC>0	65,32%
Average OC3	5.474,31 €	Flights DEC>0	11,71%

Average DOC	75,12 €	Flights TS>0	64,77%
Average EC1	873,53 €	Total DOC	43.513.798 €
Average EC3	870,91 €	Total DEC	-1.514.702 €
Average DEC	-2,62 €	Total TS	41.999.096 €

Figure 3 presents an histogram of the distribution of operational costs savings (DOC). It is possible to appreciate that a remarkable 4% of flights have DOC=0. In the histogram, extreme cases have been neglected in order to visualise more appropriately the information. For en route charges savings (DEC), 56.1% of flights have DEC=0. This set includes domestic flights, and as all international flights that have the same intersection points with the ECZ in planned and performed flights. For the rest of flights, the 98% of DEC values are between -500 € and 500 €.

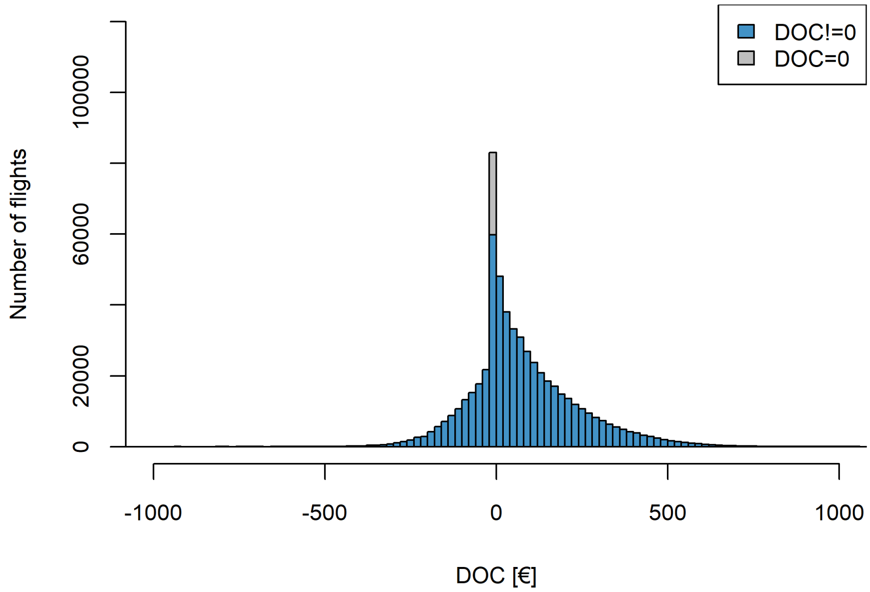

Figure 3 – DOC histogram

We can draw two conclusions from these results. First, airlines are economising from OC systematically, and with a considerable amount. Second, EC savings are not supposing gains for airlines. Therefore, it is possible to assert that there is no generalised strategy among airlines to reduce ECs systematically.

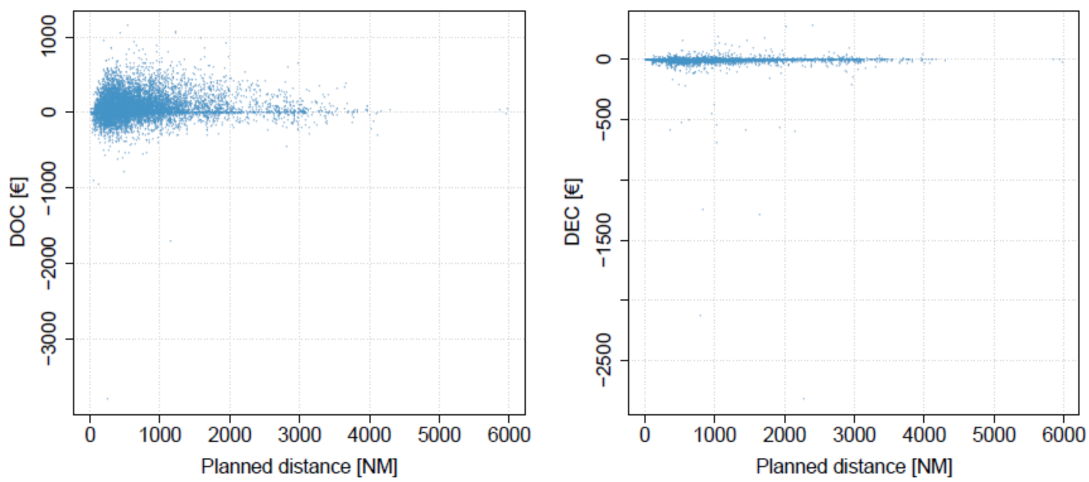

Figure 4 – DOC (left) and DEC (right) vs distance planned to fly

Figure 4 presents the values of DOC and DEC as a function of the total distance planned. By the analysis of distance and since it is the unique variable to compute OC, it is possible to observe that DEC is totally independent from the distance planned to fly and that DOC savings are relatively proportional to distance for distances up to the higher ones, from which an attenuation factor is appreciated. This can be interpreted as the flexibility of a longer flight of reducing the planned distance, which seems not to affect considerably longer flights. It can be asserted that, on average, airlines are saving 0,10 € per nautical mile from trajectory deviations.

This fact is inherently related to the analysis that has been carried out between domestic and international flights. Domestic flights (flights that overfly a unique ECZ) have an sTS value of 52,25 €, and international flights, 80,77 €.

As well, a territorial analysis has been carried out regarding the En-route Charging Zones (ECZ) and airports in order to observe if there were patterns of observed total savings (sTS) at arrival and departure. Therefore, the most plausible contention would be to assert that differences of sTS per region or airport at arrival or departure are more linked to the intrinsic nature of the routes performed in those flights than to a deliberateness of airlines.

In Table 2 are presented the results for the top 25 airlines, according to its Global Share (GS) of flights offered. OVR represents the relative overrepresentation of airlines in terms of Total Savings TS in comparison to its global share GS.

The most important variables to analyse could be dsTS and OVR. This factor represents the savings achieved by each airline per each nautical mile planned to fly. As it is possible to see there is an important disparity of savings among airlines, although it seems that there is a tendency for LCC to have larger values of savings.

Table 2-Airline results

AO	DOC [€]	DEC [€]	TS[€]	GS [%]	OVR [%]	sTS [€/fl]	d[1] [NM]	dsTS
RYR	6.690.796	-204.450	6.486.346	9,40	64,30	119,12	750	0,16
EZY	2.715.484	-51.351	2.664.133	6,68	-5,04	68,85	612	0,11
DLH	2.252.980	-156.562	2.096.418	6,28	-20,52	57,65	522,43	0,11
THY	1.024.654	-28.913	995.741	5,90	-59,82	29,16	790,69	0,04
AFR	1.436.130	-23.056	1.413.074	3,81	-11,69	64,11	580,75	0,11
SAS	1.139.351	-55.490	1.083.861	3,38	-23,65	55,33	448,93	0,12
EWG	1.683.011	-117.708	1.565.303	2,83	31,70	95,33	511,96	0,19
KLM	502.422	-65.430	436.992	2,81	-62,97	26,83	537,17	0,05
VLG	1.079.669	-25.051	1.054.618	2,55	-1,53	71,49	565,03	0,13
BAW	45.060	-26.386	18.674	2,51	-98,23	1,28	846,4	0,00
AZA	1.864.375	-14.858	1.849.517	2,43	81,22	131,55	478,13	0,28
WZZ	1.915.445	-79.545	1.835.900	2,40	82,14	132,31	829,79	0,16
PGT	353.070	-9.882	343.188	2,26	-63,84	26,19	642,67	0,04
BEE	16.306	-8.302	8.004	1,84	-98,96	0,75	281,27	0,00
SWR	1.030.639	-40.606	990.033	1,78	32,43	95,9	545,42	0,18
LOT	2.312.933	-56.330	2.256.603	1,66	223,67	235,31	484,6	0,49
TAP	1.456.528	-17.564	1.438.964	1,64	108,91	151,02	813,16	0,19
AFL	658.581	-22.397	636.184	1,63	-7,07	67,38	1.179,00	0,06
AUA	83.131	-28.310	54.821	1,59	-91,79	5,95	457,25	0,01
FIN	558.986	2.533	561.519	1,53	-12,62	63,33	616,12	0,10
NAX	680.342	-79.597	600.745	1,50	-4,64	68,99	628,3	0,11
WIF	732.052	-1.885	730.167	1,48	17,47	85,43	157,96	0,54
IBK	934.235	-96.665	837.570	1,29	54,59	111,81	1.043,04	0,11
AEA	444.835	-1.405	443.430	1,22	-13,46	62,68	459,64	0,14
QTR	369.326	-10.467	358.859	1,11	-23,02	55,65	2.408,57	0,02

We have also analysed cost saving by time slot has been also analysed. Figures 5 to 7 present sTS values for flights arriving and departing to/ from that some relevant ECZs. Time slot of

[1] Mean distance.

these countries is expressed in UTC. In spite of the fact that these countries have different time zones, they are close to UTC +0.

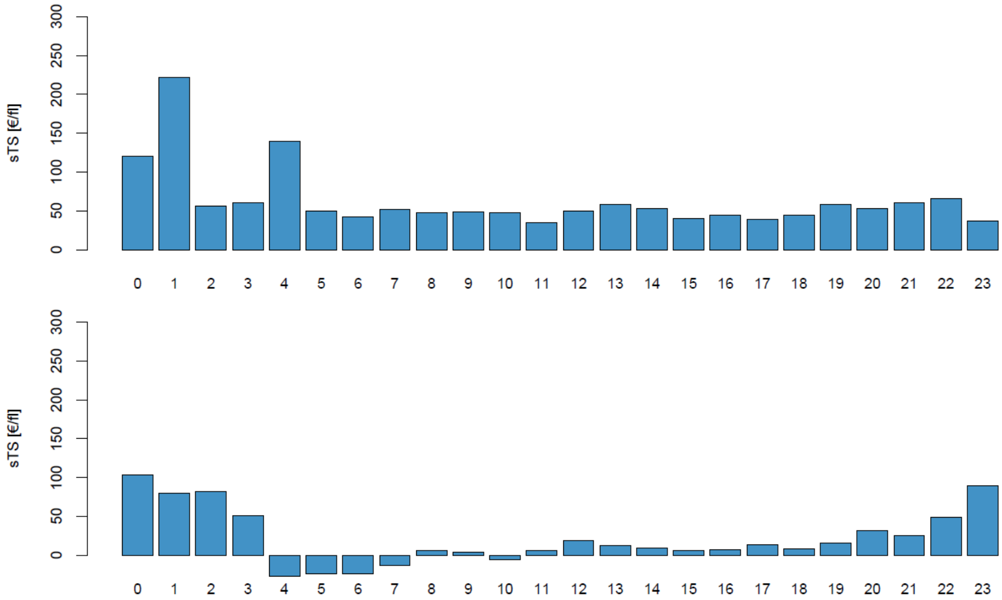

Figure 5 – sTS in EG per time slot for departing (top) and arriving (bottom) flights

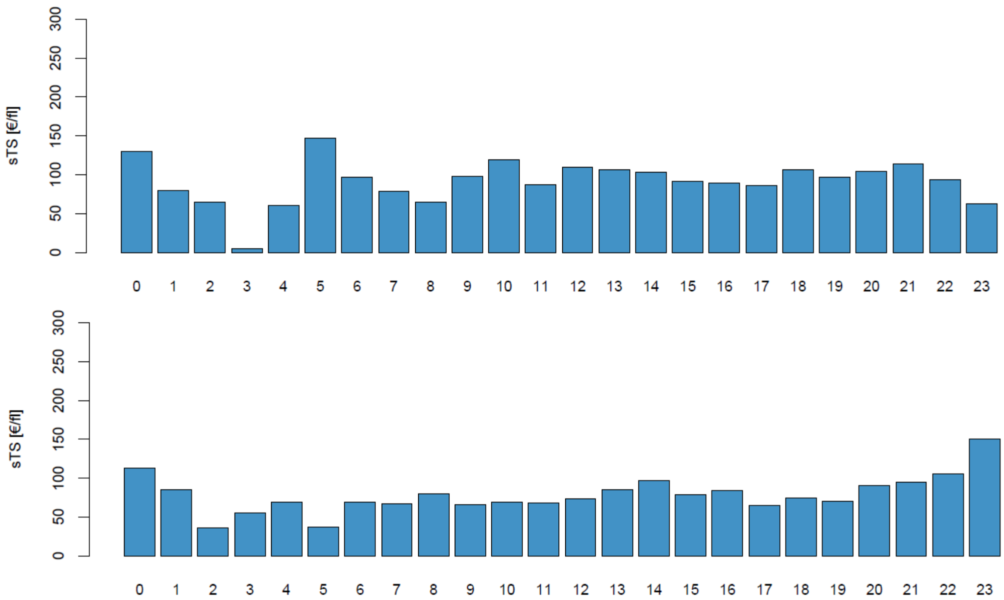

Figure 6 – sTS in LE per time slot for departing (top) and arriving (bottom) flights

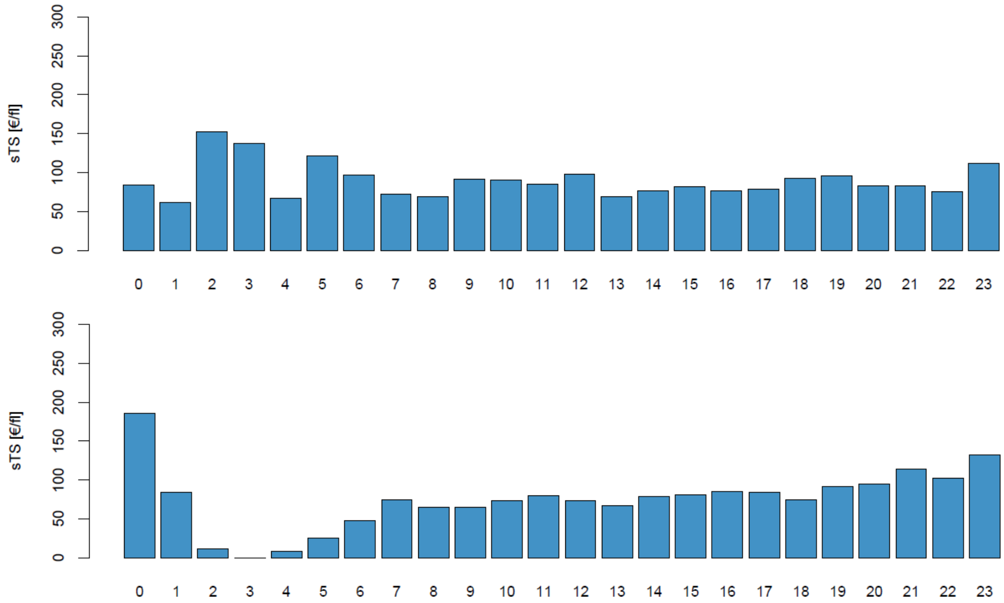

Figure 7 – sTS in ED per time slot for departing (top) and arriving (bottom) flights

For all cases, sTS values tend to be higher for night time hours. This replicates the results of Bongiorno et al. (2017), who found that reductions of the distance planned to fly in relation to distance flown are higher during night time than day time.

Conclusions

This study is focused on the analysis of deviations from planned flights in the European space network hypothetically triggered by economical motivations of airlines. Both costs must be treated differently, since, in the case of operational costs (OC), aircraft operators pay for what they actually fly and, in the case of en route charges (EC), they pay for what they plan instead of for what they perform in reality. We have found that operational costs have outstandingly more weight than en-route charges, not only regarding the global cost of an average flight, but also in terms of average savings. Therefore, it is possible to assert that there is no generalised strategy among airlines to reduce en-route charges asking for deviations of the planned route. In fact, the current system seems to be slightly disadvantageous for airlines. On the other hand, airlines are achieving savings of operational costs regularly.

It has been found that the saving of operational costs from trajectory deviations is of 0.10 € per each nautical mile planned to fly, although higher savings are achieved in longer flights. This can be triggered by more flexibility of operations of longer flights. As well, as it was found in Bongiorno *et al.* (2017), flights are commonly shorter on average in their real performance than in their planning. This causes higher savings in OC since they are intrinsically related to distance flown. WE have also found that night-time flights tend to be shorter than planned ones in a major way than in day-time flights. In night time there is lower-traffic than in day time, which would provide more flexibility to the system.

Results show that low-traffic conditions and longer flights seem to be triggering higher savings. These savings come from the interaction between air traffic controllers and pilots, in a join effort to look for operating more efficiently without compromising safety and capacity (Bongiorno *et al.*, 2017).

The analysis of flight deviations by airline (see Table 2) see consistent patterns regarding flight deviations. Airlines with similar business models (e. g. FSC, LCC, RC) have different values of total savings. This suggests that airlines could have distinct strategies concerning cost reductions from flight deviations, that would lead pilots of different companies to behave distinguishably when facing possibilities of reducing planned distance when performing the flight.

Being a first study of the impact of flight trajectory deviations in airline costs, this research has some limitations. The first limitation concerns the time scope chosen, as we have only taken one month of flights (December 2018) for computational capability and data availability reasons. Examining flight deviations on a longer temporal scope would lead to examine seasonal patterns of airline's behaviour concerning trajectory deviations. A second limitation is that we have not examined the effect of traffic congestion on trajectory deviations. These research limitations can turn into new avenues for research on strategies followed by airlines concerning trajectory definition.

References

Alderighi, M., Cento, A., Nijkamp, P., & Rietveld, P. (2012). Competition in the European aviation market: the entry of low-cost airlines. *Journal of Transport Geography*, *24*, 223–233.

Ashford, N. J., Mumayiz, S., & Wright, P. H. (2011). *Airport engineering: planning, design, and development of 21st century airports*. John Wiley & Sons.

Bongiorno, C., Micciche, S., Mantegna, R., Gurtner, G., Lillo, F., & Pozzi, S. (2015). Adaptative air traffic network: statistical regularities in air traffic management. In *11th USA/Europe Air Traffic Management Research and Development Seminar, ATM 2015*. EUROCONTROL.

Bongiorno, C., Gurtner, G., Lillo, F., Mantegna, R. N., & Miccichè, S. (2017). Statistical characterization of deviations from planned flight trajectories in air traffic management. *Journal of Air Transport Management*, *58*, 152-163.

Bourguignon, F., & Darpeix, P. E. (2016). Air traffic and economic growth: *the case of developing countries* https://halshs.archives-ouvertes.fr/halshs-01332085/

Castelli, L .; Pesenti, R .; Schiratti, S. and Ukovich, W., 2004, Study of the impact of innovative route charge schemes considering ATC and airlines new perspectives, *Final Report of the CARE Innovative Action Project*, University of Trieste / DEEI, Italy

Castelli, Lorenzo, Bolić, T., Costanzo, S., Rigonat, D., Marcotte, E. and Tanner, G. (2015). Modulation of en-route charges to redistribute traffic in the European airspace. *Fifth SESAR Innovation Days.*

CRCO (2019). *Central Route Charge Office Customer Guide to Charges.* https://www.eurocontrol.int/sites/default/files/publication/files/customer-guide-charges-20-feb-2019.pdf (retrieved 10/05/2019).

CRCO (2018). *Information Circular No. 2018/06: Value Added Tax (VAT) on route charges.* https://www.eurocontrol.int/articles/information-circulars (10/05/2019)

Dalmau, R., & Prats, X. (2015). Fuel and time savings by flying continuous cruise climbs: Estimating the benefit pools for maximum range operations. *Transportation Research Part D: Transport and Environment*, 35, 62-71.

Dalmau, R. ., Melgosa, M., Vilardaga, S., & Prats, X. (2018, June). A fast and flexible aircraft trajectory predictor and optimiser for atm research applications. In Proceedings of the 8th international conference for research in air transportation (ICRAT).

Delgado, L., 2015, "European route choice determinants: Examining fuel and route charge trade-offs", 11th USA / Europe Air Traffic Management Research and Development Seminar, Lisbon, Portugal.

Deschinkel, K., Farges, J. L., & Delahaye, D. (2002). Optimizing and assigning price levels for air traffic management. *Transportation Research Part E: Logistics and Transportation Review*, 38(3-4), 221-237.

EUROCONTROL (2018). *DDR2 Reference Manual for General Users 2.9.5*. 25th ed., T. Champougny and DDR2 Developers, Eds. Melike Atik.

EUROCONTROL (2019).*EUROCONTROL Specifications for harmonized Rules for Operational Air Traffic (OAT) under Instrument Flight Rules (IFR) inside controlled Airspace of the ECAC Area (EUROAT).*

Ferencová, M .; Koščák, P .; Szabó, P. .; Makó, S .; and Pilát, M., 2019, Flight Trajectory Selection Impact on the Flight Cost, *14th International Scientific Conference on New Trends in Aviation Development (NTAD)*, Chlumec nad Cidlinou, Czech Republic.

Goetz, A. R., & Vowles, T. M. (2009). The good, the bad, and the ugly: 30 years of US airline deregulation. *Journal of Transport Geography*, *17*(4), 251–263.

Patron, R. F., Kessaci, A., & Botez, R. M. (2013). Flight trajectories optimization under the influence of winds using genetic algorithms. In AIAA guidance, navigation, and control (GNC) conference (p. 4620).

Vitali, S., Gurtner, G., Valori, L., Cipolla, M., Beato, V., Lillo, F., & Mantegna, R. (2012). Statistical Regularities in ATM: Network Properties, Trajectory Deviations, and Delays Presentation of ELSA. Second SESAR Innovation Days.

Zuidberg, J. (2014). Identifying airline cost economies: An econometric analysis of the factors affecting aircraft operating costs. *Journal of Air Transport Management*, *40*, 86–95.