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THE IMPACT OF THE EU-ETS ON THE AVIATION SECTOR: COMPETITIVE E EFFECTS OF ABATEMENT EFFORTS BY AIRLINES

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The impact of the EU-ETS on the aviation sector: competitive effects of abatement efforts by airlines

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Abstract: In the next few years, it is estimated that the aviation sector will account for more than 15% of total GHG emissions against the current 5%. In order to curb emissions, Directive 101/2008/EC has included the aviation sector within the scope of the European Union Emission Trading Scheme (EU-ETS). The EU-ETS is generating additional costs for airline companies. The present article develops an original model with which to analyse the impact of EU-ETS on the aviation sector's market equilibrium. Our study expands prior research by explicitly allowing for abatement efforts in the cost function of airline companies and by highlighting interactions among strategies to reduce emissions, firm's actions in the secondary market, free allowances, and fines. The results contribute to enhancing policy makers understanding of the impact of the EU-ETS on the aviation sector also in light of its potential global-level extension that is currently under negotiation.

Keywords: EU-ETS, Aviation sector, airline competition, Cournot equilibrium, abatement effort

Highlights:

- The article provides a new model with which to assess the impact of the EU-ETS on the aviation sector;
- It provides a Cournot-Nash equilibrium generalization to n heterogeneous firms;
- The abatement effort in the cost function explicits environmental airline strategies;
- It analyses the interaction among abatement effort, free allowances, fines, secondary/auction market;
- The model predicts outputs, profits and abatement efforts also for Italian carriers.

1 Introduction

The aviation industry has experienced rapid expansion worldwide. Over the past 40 years, the global air travel volume has increased tenfold, recording a growth three times higher than that of the world's economy (IATA, 2011). Annual growth in global air transport is expected to remain at around 5% until 2030. The increase in demand for flights can be explained by a series of concurrent factors, such as the intensification of worldwide flows of trade, the rise of mass tourism, especially from emerging markets, and changes in consumers' behaviour (Gössling et al., 2012). Moreover, the deregulation and liberalisation policies that have involved the sector since the 1990s have encouraged new competitors and low-cost carriers to enter the market, thus reducing pressure on air fares and making air transport accessible also to individuals with tighter budgets (IATA, 2007; Meleo et al., 2016) . This trend is confirmed by the positive growth rate of air transport passengers in the EU-28 countries (+4.4% in 2013-2014), especially as regards Greece, Lithuania or Poland, where demand increased by more than 10% in the same period (Fig. 1).

In the EU, the number of flights increased by 80% in the period 1990-2014, and they are expected to grow further by 45% between 2014 and 2035 (EASA, 2016). This means that the sector is estimated to account for beetween 5% and more than 15% of European total greenhouse gas (GHG) emissions (Rothengatter, 2010; Capoccitti et al., 2010), the main source of the aviation sector's air pollution.

Accordingly to the base scenario of EASA (2016), future technology improvements are unlikely to balance the effect of the forecasted traffic growth, and CO2 emissions in 2035 are projected to be 44% higher than the 2005 level.

To prevent negative impacts, and to incentivise further investments in reducing GHG emissions, the Directive 101/2008/EC has included the aviation sector within the scope of the European Union Emission Trading Scheme (EU-ETS), the biggest world-wide emission trading scheme launched on 1 January 2012. The resulting political and legal debate has induced the European Commission (EC) to amend the Directive, first with Decision 2013/337/EU (the so-called "stop the clock" derogation) and then with Regulation 2014/421. The EU-ETS currently covers all flights arriving in and departing from the European Economic Area (EEA), regardless of the nationality of airline companies (Meleo et al., 2016)[1].

However, a new global agreement to implement a single global market-based solution is under negotiation by the International Civil Aviation Organisation (ICAO). At the beginning of this

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[1] The derogation stated first that all flights within the EEA were part of the EU-ETS, and that residual flights were under exemption in 2013. Since 2014, all flights have been under the EU-ETS, including flights outside the EEA but only for the kilometres travelled within the EEA.

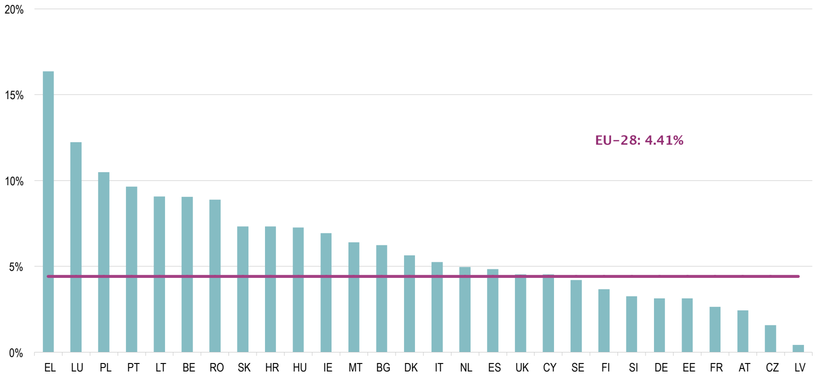

Figure 1: Percentage growth in air transport passengers in EU member states in 2013-2014. Source: Eurostat database

year, the EC launched a new public consultation on market-based measures to tackle the climate change impacts of international aviation emissions in relation to the EU-ETS.

One of the issues most debated is the EU-ETS's effects on market equilibrium and on the competitiveness of airline companies because of the additional costs that they must bear in order to comply with the Directive. Thorough understanding of how airline companies are responding to the EU-ETS is crucial so that the current scheme can be fine-tuned also in view of its possible extension to international aviation. How airlines modify their supplies is important from both the efficiency and environmental effectiveness perspectives. While the former concerns the possibility to adopt least-cost regulatory measures, the latter involves attainment of the planned reductions in GHG emissions. Changes in routes and network configurations, as well as in the frequency of service and departure schedules on each route served by single airlines, may also affect final consumers, especially when those routes are vital for the economic development of the region that they serve and if public service obligations are imposed.

As a market-based instrument, the EU-ETS provides the incentive to reduce GHG emissions in the most efficient way by means of carbon price signals (Baumol and Oates, 1988; Ryan, 2011; Rydge, 2015). Once the permits have been issued, the firm compares the carbon price and the marginal abatement cost (MAC), i.e. the marginal cost necessary to reduce emissions by one pollution unit. In the case of a firm with CO_2 emissions above the mount stated in the permit issued, if the carbon price is lower than the MAC, then this firm will buy permits from the market to offset its emission goal. On the other hand, if the carbon price is higher than the MAC, then the firm will invest to reduce its CO_2 emissions, i.e. to improve its energy efficiency. Finally, firms can sell the permits that exceed their actual emissions, and thereby earn a profit. This “incentive scheme” implies that firms should take into account in their cost function of some additional components that can vary according to the allocation method (% of emission permits grandfathered and auctioned), the amount of the “green” investment, and the allowances price (the carbon price).

The economic literature has thoroughly investigated the effects of the EU-ETS on economic performance and competitiveness, and innovation (see Ellerman et al. (2015); Martin et al. (2015)). Focusing on the aviation sector, some authors have found that the EU-ETS generates a reduction of profit margins (Malina et al., 2012; Girardet and Spinler, 2013), a loss of market shares, or a reduction of companies’ growth rates (Faber and Brinke, 2011; Anger and Köhler, 2010), and a change in barriers to entry (Barbot et al., 2014). These effects may be even more important when airlines cannot off-set environmental costs by passing through additional costs onto air fares or by using profits gained on extra-European routes[2].

Other studies (Sgouridis et al., 2011; Sheu and Li, 2013) have focused on the incentives provided by the EU-ETS to invest in environment-friendly solutions. They stress that innovation for the aviation sector is rather limited compared to other industries, and that it relies mainly on technological efficiency (i.e. modernizing the fleet to incorporate more fuel-efficient aircraft), operational efficiency (i.e. engine washing, less use of auxiliary power units) and the introduction of alternative fuels.

The environmental effects, even if positive, are still too small (Anger and Köhler, 2010; Vespermann and Wald, 2011; Malina et al., 2012; Chin and Zhang, 2013), possibly because the climate impact of aviation is not entirely solely by CO_2 emissions (Dessen et al., 2014; Preston et al., 2012).

To the best of our knowledge, the literature does not provide a generalization of the Cournot-Nash equilibrium to n firms to assess the actual and potential effects of the EU-ETS on airline market competition. Only recently, have some contributions started to investigate this approach (Barbot et al., 2014; Chin and Zhang, 2013). Barbot et al. (2014) show that the ETS may affect potential competition since the share of capped allowances allocated initially for free may be used by incumbent air operators to deter entry into the market. Chin and Zhang (2013) use a Cournot model to assess changes of output and efficiency level due to the different allowance allocation methods. They emphasize an increase in both profits and operating costs for airlines. While focusing on competitive effects, changes induced by the emission trading scheme on innovation efforts have not yet been formally considered in equilibrium modelling. Likely positive impacts

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[2] The pass-trought on final prices is a strategy announced and enforced by Ryanair with a charged fare of 0,25 Euros per flights (Elsworth and MacDonald, 2013).

on innovation in low carbon technologies and energy efficiency constitute one of the main factors explaining the adoption of market-based measures addressing GHG emissions. To fill this gap, the present paper proposes an extension of existing models with which to explore how the market equilibrium changes as a consequence of airlines' strategies in response to incentives provided by the EU-ETS.

Starting from the study by Chin and Zhang (2013), and the model developed by Meleo et al. (2016), the paper focuses on different equilibrium solutions that aviation companies could achieve given the additional costs and innovation incentives provided by their inclusion within the scope of the EU-ETS. The analysis is developed by referring to various competitive assumptions about the market structure. There assumptions are consistent with those in the previous literature and with the characteristics of the aviation sector worldwide. In particular, the first assumption relies on the presence of n airline operators that compete on the quantity of emissions. The latter directly depends on the total kilometres of flights supplied, thus assuming a Cournot oligopoly market structure. This base model compares equilibria before and after the introduction of the EU-ETS in the case of airline homogeneity. Thereafter, competitive strategies of other type are considered, namely perfect collusion (monopoly) and deviation from collusion. Finally, strategies based on heterogeneous firms are analysed.

In order to take explicitly account of the changes in abatement efforts generated by the emission trading scheme, a component additional to the cost function is introduced. More specifically, the unitary cost function of airlines is modified by including an abatement cost representing any investment intended to reduce emissions, such as the purchase of more fuel-efficient planes, the optimization of routes, etc.

We test the model's predictions for output, profit and innovative incentives on Italian carriers. Italy is one of the major air transport markets in the EU in terms of both number of passengers and volume of freight and mail. Like other European countries, it has experienced significant changes in the past fifteen years (OECD, 2014). In the period 2001-2015, total passengers transiting through Italian airports grew by 74.5%, amounting to almost 157 million. As a consequence, GHG emissions increased as well. According to ISPRA (2016), GHG emissions rose by 19.1% from 1990 to 2014, and they currently represent about 1.8% of the national total emissions from transport, and about 0.5% of the national GHG total. Italian carriers, which are already encountering difficulties in adapting to the new regulatory framework and in making the improvements needed to operate more efficiently, may provide an interesting case to evaluate the impact of the EU-ETS at national level in the case of heterogeneous firms.

Several implications, which are particularly useful from an operational perspective, can be derived to support policy-making decisions through better understanding of the overall effects of the EU-ETS. Our results highlight a trade-off in determining profits between the efficiency cost of individual carriers and the share of allowances distributed free of charge. From a regulatory perspective, the higher the latter, the lower are the incentives to reduce GHG emissions. Moreover, the higher the number of carriers competing on the same air route, the lower is the increase of profits under a Cournot oligopoly or a market collusion. Still ambiguous is the effect of different strategies adopted by airline companies in the allowance market.

The remainder of the article is organized as follows. Section 2 describes the regulatory background with, first, a brief description of the EU-ETS's functioning for the aviation sector and then explanation of the model developed for the purposes of this paper. Section 3 derives equilibria according to different competitive assumptions, and it proposes an empirical application of the model to the Italian aviation sector. Finally, in section 4 policy implications derived from the modelling results conclude the article.

2 Background and methods

In this section the main characteristics of the EU-ETS policy are illustrated (section 2.1), and then a theoretical model is constructed in section 2.2.

2.1 The basics of EU-ETS and aviation

As mentioned in Section 1, the aviation sector has been within the scope of the EU-ETS since 1st January 2012. The rules introduced by Directive 2008/101/EC are rather peculiar. They state that all flights departing from and arriving at an EEA airport must be covered by emission permits, regardless of the country in which the airline company is registered. This means that also extra-European companies must comply with the EU-ETS framework.

However, after the fierce debate that followed the legislation, the EC decided to amend the Directive by Decision 2013/337/EU, and, later, by Regulation 2014/421. The EU-ETS is currently enforced only for flights within the EEA until 2016, while waiting for a global agreement to come into force under the supervision of the ICAO[3].

As briefly mentioned in the introduction, the EU-ETS is a market-based instrument working as a "cap and trade" system. It adopts a "top-down" mechanism already applied for industrial plants under the system. The emission cap the EC set at an European level is, however, different from the one set for industrial plants. For 2012, the EC had to distribute a number of permits

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[3] After the 2013 Decision, the cap was changed to 59 per cent of free allowances returned to the EC. This means that, for 2013, out of the 173.817.206 permits formerly granted, only 70.882.854 were issued (European Environmental Agency-EEAg database and Elsworth and MacDonald (2013)).

corresponding to 97 per cent of average aviation sector emissions registered in Europe in the period 2004-2006. In the following years (2013-2020), the cap was reduced to 95 per cent of the same historical emissions. As regards the allocation method, in 2012 15 per cent total permits issued by the EU had to be auctioned, and 85 per cent distributed for free. In 2013-2020, 82 per cent of the cap must be allocated free of charge, 15 per cent by auctions, and 3 per cent collected in the new entrants' reserve.

Once the cap has been defined, the system works at a Member State level. Every aircraft operator is linked to a Member State ("administering Member State") which corresponds to the country where the company is registered or to the European state where the aircraft operator performs the highest number of flights. For permits being auctioned, Directive 2008/101/EC states that, for 2012, the emissions to consider for each Member State are the data recorded in 2010, and, for the years thereafter, the emissions recorded 24 months before the auctioning base year. For the allowances distributed free of charge, the EC follows an approach based on a benchmark: emission permits to be assigned are fixed and obtained as a certain number of allowances due for every tonne-km. Therefore, the aircraft operators receive from the national EU-ETS authority a number of emission permits obtained by multiplying the benchmark factor by the tonne-km registered for the period.

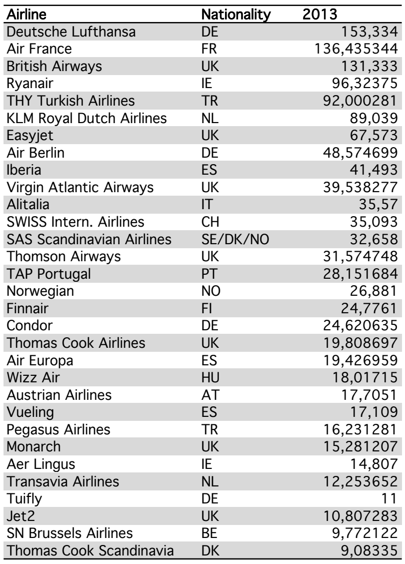
By 30th April of each year, every airline operator must return emissions to the national competent authority of the administering Member State. In the case of deficit, airlines must buy the lacking allowances on the carbon market: otherwise, a penalty of 100 Euros per tonne of CO_2 is enforced. In addition to the penalty, the airlines must purchase the allowances not surrendered in any case.

This scenario is formalized in terms of firms' cost functions and related payoffs in the sections below.

2.2 The methodology

The aviation market has some distinctive characteristics that must be taken into account to analyse the effects of the EU-ETS on market equilibrium and competitiveness.

The number of airline operators in Europe is rather limited, as suggested by Table 2 which shows a ranking of the major European airline companies in 2013. In addition, national markets are usually controlled by a small group of firms (i.e. in Italy there are only seven active airline companies under the EU-ETS) and characterized by significant barriers to entry that discourage potential competitors from adopting entry strategies (Barbot et al., 2014). Thus, the aviation sector typically assumes an oligopolistic structure rather than a competitive one, and firms compete over the share of flights and of tonne-km flown during the year (Chin and Zhang,



Airline	Nationality	2013
Deutsche Lufthansa	DE	153,334
Air France	FR	136,435344
British Airways	UK	131,333
Ryanair	IE	96,32375
THY Turkish Airlines	TR	92,000281
KLM Royal Dutch Airlines	NL	89,039
Easyjet	UK	67,573
Air Berlin	DE	48,574699
Iberia	ES	41,493
Virgin Atlantic Airways	UK	39,538277
Alitalia	IT	35,57
SWISS Intern. Airlines	CH	35,093
SAS Scandinavian Airlines	SE/DK/NO	32,658
Thomson Airways	UK	31,574748
TAP Portugal	PT	28,151684
Norwegian	NO	26,881
Finnair	FI	24,7761
Condor	DE	24,620635
Thomas Cook Airlines	UK	19,808697
Air Europa	ES	19,426959
Wizz Air	HU	18,01715
Austrian Airlines	AT	17,7051
Vueling	ES	17,109
Pegasus Airlines	TR	16,231281
Monarch	UK	15,281207
Aer Lingus	IE	14,807
Transavia Airlines	NL	12,253652
Tuifly	DE	11
Jet2	UK	10,807283
SN Brussels Airlines	BE	9,772122
Thomas Cook Scandinavia	DK	9,08335

Figure 2: Major European Airlines with respect to 2013 revenue Passenger-kilometres (in billions). Source: Association of European Airlines, Ascend, International Air Transport Association, air companies, own estimates.

2013). As a consequence, in this paper, the aviation market is modelled via a simultaneous game à la Cournot where firms compete on the share of tonne-km flown during the year, as suggested by the economic literature from both a theoretical (Barbot et al., 2014; Basso, 2008; Chin and Zhang, 2013; Verhoef, 2010) and an empirical (Brander and Zhang, 1990; Oum et al., 1993) perspective.

The model is developed by introducing the simplifying assumptions described below. Firstly of all, it is assumed that the aviation industry is composed of n aircraft operators, with n limited to be such that a competitive market structure is not feasible. Each airline operator maximizes its profit choosing its output in terms of tonne-kilometres flown (namely q_i, $\forall\, i = 1, \ldots, n$), and the efficiency level (e_i). The latter describes the efficiency gains due to the emission reductions induced to comply with the EU-ETS. Secondly, the aviation industry is assumed to be a net buyer of allowances, and the carbon price and sanctions are considered exogenous variables (Anger and Köhler, 2010).

The EU-ETS Directive identifies two different phases. The first one, which involves computation of the historical emissions to set the cap, is termed the "benchmark period" (here with subscript B for variables identification). The second period refers to the moment in which free allowances are allocated among firms and is named the "EU-ETS period" (with subscript E for variable identification). In other words, this second period represents the moment in which the EU-ETS incentive mechanisms effectively start to induce changes in the aviation sector. In this scenario, airline companies compete in the market and, at the same time, they have to manage constraints imposed by the EU-ETS Directive.

For the purposes of this paper, additional simplifying assumptions concerning the demand and the cost functions are needed. As suggested by the literature (Barbot et al., 2014; Basso, 2008; Brander and Zhang, 1990; Chin and Zhang, 2013; Girardet and Spinler, 2013; Oum et al., 1993; Verhoef, 2010), it is assumed that the market is characterized by an inverse linear demand function:

$$P(Q) = a - bQ$$

where P is the price, Q is the quantity demanded by consumers. Moreover a, b, with $b \geq 0$, represent, graphically speaking, respectively the intercept and the slope of the demand function. If we consider the direct demand function in the form $Q = a - \frac{1}{b}P$, then the coefficient $-\frac{1}{b}$ represents the reaction of Q, the demand, according to an increase of 1 monetary unit in the ticket price. Moreover, $Q = \sum_{j=1}^{n} q_j$ identifies the total quantity in terms of flights offered by the aviation industry (i.e. n producers).

Even if this hypothesis is widely accepted in literature, it is important to recall the limits of considering this type of demand function, although they do not affect the analysis on equilibria variation developed in this paper. The first limit concerns the linearity assumption which neglects the role played by air mail and air freight traffic, and which does not differentiate passenger demand into business, tourism and low price passengers, thus losing information on passengers' reactions to price variations[4]. Even if this appears to be a major limit, the literature (IATA, 2008) suggests that price variation is currently influenced by two main dynamics: "Passengers are becoming increasingly sensitive to price, led by the boom in low cost travel, the transparency brought by the Internet and the intense competition on deregulated markets. But, passengers are also becoming less sensitive to price, as increasingly lower air travel prices, in real terms, mean that the air travel price itself becomes a smaller and less important part of the total cost of a typical journey"[5].

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[4] The aviation demand literature (Gillen et al., 2007; Brons et al., 2002) develops and reviews specific demand functions for each type of consumers the purpose being to account for their different behaviours according to a change in the price.

[5] This is principally associated with a two-stage travel decision in which passengers first decide to buy an air ticket and then define the complementary goods or services related to the travel. However, the elasticity estimation can be calculated only up to the final price paid by the passenger. This is why we speak of a derived demand (IATA, 2008; Anger and Köhler, 2010). So far, also the definition of the elasticity is not unique in the air transport sector.

In addition to the use of an inverse linear demand function, the sector is assumed to have a homogeneous quadratic unitary cost function as suggested by the economic literature (Barbot et al., 2014; Clemez, 2010; Dijkstra and Rübbelke, 2013).

In the specific case of the aviation sector, and according to the functioning of the EU-ETS, this unitary cost function depends on the abatement effort made to improve environmental efficiency (e) and on the marginal cost α that is independent from e, i.e. the amount of all the other variables' unitary costs that are uncorrelated with the effort. The abatement effort includes any investment intended to reduce emissions, i.e. the purchase of a new low CO_2 emissions airplane, the optimization of air routes, etc[6]. Hence, the unitary cost function assumes the following form

$$c(e_i) = \alpha + \beta e_i^2 \;\; \forall\, i = 1, \dots, n. \tag{1}$$

where $\alpha, \beta \geq 0$ reflect the assumption of homogeneity among airline operators, given that they are not indexed by i, and e_i assumes non-negative values, i.e. $e_i \geq 0$. The linearity of the cost function to the efficiency level is therefore clear from this formulation. Relaxing this assumption, β could be defined "firm specific", i.e. β_i for the ith airline operator, highlighting differences among companies in terms of effort costs. Furthermore, the efficiency level e_i chosen by the player i is defined as the ratio between tonne-kilometres and the quantity of fuel consumed. The effort can imply different "green" actions as mentioned in the introduction. Thus e_i itself could be appropriately modelled to weigh those actions and their contribution to emissions reduction. Let us take as an example the use of biofuels instead of traditional fuels such as Jet-A and Jet A-1. Nowadays, companies, for instance Lufthansa, select advanced liquid biofuels that allow a reduction in CO_2 emissions. In this case the abatement effort is equal to the price of the biofuel that could be appropriately weighted in e_i with respect to other forms of emissions abatement.

Given this general set-up description, profit function differences between the benchmark and the EU-ETS period are discussed below. In the benchmark period (denoted with the subscript B), under the described assumptions, the profit function for the generic i^{th} aircraft operator is

$$\pi_{i,B} = \left(a - b \sum_{j=1}^{n} q_{j,B} \right) q_{i,B} - (\alpha + \beta e_{i,B}^2) q_{i,B}. \tag{2}$$

For the second period (denoted with the subscript E), the profit function differs from the (2) because the EU-ETS defines new variables entering the profit and cost functions. Thus, the

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[6] In this paper, the term "efficiency" indicates the extent to which the abatement effort reduces pollutant emissions of airlines.

second period profit function for the i^{th} aircraft operator is

$$\pi_{i,E} = \left(a - b\sum_{j=1}^{n} q_{j,E}\right) q_{i,E} - (\alpha + \beta e_{i,E}^2)q_{i,E} - f(q_{i,E}, e_{i,E}, \mathbf{P}, \boldsymbol{\delta}). \tag{3}$$

with

$$f(q_{i,E}, e_{i,E}, \mathbf{P}, \boldsymbol{\delta}) = \Delta\left[\frac{q_{i,E}}{e_{i,E}} - \gamma\left(\frac{q_{i,B}}{\sum_{j=1}^{n} q_{j,B}}\right)\right] \tag{4}$$

where $\Delta = (P_a\delta_a + P_m\delta_m + P_r\delta_r - P_m\delta_s)$. Equations (3) and (4) well reflect the choices of a company under the EU-ETS because $f(\cdot)$ takes into account the case in which permits are purchased by auction (a) or on the carbon or secondary market (m), and the situation in which companies incur fines (r) or sell the permits in the case of surplus given the vectors $\mathbf{P} = [P_a \quad P_m \quad P_r]$ and $\boldsymbol{\delta} = [\delta_a \quad \delta_m \quad \delta_r \quad \delta_s]$.

In details, P_a and δ_a are the auction price and the rate of permits purchased from auctions respectively, P_m is the allowances market price that the aircraft operator has to pay on the carbon market in the case of allowances deficit, δ_m is the proportion of permits that are bought on this market. In the same way, P_a and δ_a indicate the auction price and the fraction of permits obtained from auctions, and P_r and δ_r the unitary sanction enforced on non-compliant companies and the rate of allowances not returned to the European Commission. To take into account that allowances must be surrendered in any case even after the payment of the sanction, the price P_r is composed of the unitary sanction s and the unitary market price P_{m,t^*} that will be paid by the non-compliant airline operators to buy the permits to cover these additional emissions at a certain future time t^*, i.e. $P_r = s + P_{m,t^*}$.

The equation $f(\cdot)$ includes also the case in which firms record an allowances surplus that can be sold in the carbon market to gain a profit. In details, δ_s is the rate of permits sold at the market price P_m. Finally, γ represents the fraction of free allowances allocated to the company, according to the emissions recorded in the benchmark period (B) as described in section 2.

Note that there is a relationship among the variables described above that can be defined, i.e. $\delta_r = 1 - \delta_a - \delta_m + \delta_s$ and, as a consequence, the following conditions must hold true: $\delta_a \in [0,1]$, $\delta_m \in [0,1]$, $\delta_r \in [0,1]$ and $\delta_s \in [0,1]$. In particular, $\delta_s = 0$ where the company registers an allowances deficit, which means that it is polluting more than the quantity of allowances allocated free of charge $\delta_s > 0$ if and only if $\frac{q_{i,E}}{e_{i,E}} - \gamma\left(\frac{q_{i,B}}{\sum_{j=1}^{n} q_{j,B}}\right) < 0$ with $\delta_m = \delta_a = \delta_r = 0$.

Finally, the second term of (4) represents the ratio of emissions not covered by the allowances allocated for free. In particular, as suggested by Chin and Zhang (2013), the generic i^{th} airline operator has $\frac{q_{i,E}}{e_{i,E}}$ of permits to comply with the regulation, i.e. the ratio of allowances in the benchmark period given the fraction $\gamma\left(\frac{q_{i,B}}{\sum_{j=1}^{n} q_{j,B}}\right)$[7].

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[7] For an accurate illustration of the briefly described model in terms of estimation and forecast of EU-ETS

As regards the current aviation sector under the EU-ETS, apart from the Germany, the United Kingdom and Poland, in the rest of the EU, permits are only bought and sold on the secondary market and not via auctions. For these reasons, recalling that this model takes into account companies with allowances deficit, another simplifying assumption could be considered, namely $\delta_a = \delta_s = 0$. This induces $\delta_m = 1 - \delta_r$ and $\Delta = \delta_m(P_m - P_r) + P_r$ (such an example is proposed in section 3.2).

Given this framework, in the next section we derive equilibria before and after the EU-ETS, with specific aviation market structures: the Cournot oligopoly (Proposition 1 and 2), monopoly (Proposition 3), perfect collusion (Proposition 4) and, finally, the assumption of non-homogeneous firms (extension of Propositions 1 and 2 in section 3.1).

3 Results and Discussions

This section aims to derive and discuss potential competitive effects of the EU-ETS on the aviation sector also taking into account the innovation incentive provided by system. The first step is description of the different aviation sector equilibria in the Cournot-Nash framework (Dutta, 1999; Gibbons, 1992) before and after the introduction of the EU-ETS, respectively the benchmark period (B) and the EU-ETS period (E). Let us first consider a Cournot oligopoly aviation market, keeping the cost functions described in the previous section. Equilibria are presented through the derivation of payoffs, quantities and prices in the first two Propositions. They are associated respectively with the period before and after the EU-ETS. The following proposition derives equilibrium in the benchmark period.

Proposition 1 *In the Cournot-Nash equilibrium for the benchmark period, the payoff for the* i^{th} *airline company is equal to*

$$\pi_{i,B} = \frac{1}{(n+1)^2 b}(a-\alpha)^2 \quad \forall\, i = 1, \ldots, n. \tag{5}$$

Proof. The maximization of (2) determines reaction curves for airline operators. In particular, denoting the quantity offered by the other companies with $q_{-i,B} = \sum_{j \neq i} q_{j,B}$, the reaction curve $\forall\, i = 1, \ldots, n$, equals to

$$R_{q_{i,B}}(q_{-i,B}) = \frac{1}{2b}\left(a - bq_{-i,B} - \alpha - \beta e_{i,B}^2\right) \tag{6}$$

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aviation industry costs, revenues, and welfares see Meleo et al. (2016).

inducing a Cournot-Nash equilibrium output

$$q_i^B = \frac{1}{(n+1)b}\left[a-\alpha-\beta\left(ne_{i,B}^2-\sum_{j\neq i}e_{j,B}^2\right)\right] \quad \forall\, i=1,\ldots,n. \tag{7}$$

Simply, the total quantity sold on the market is

$$Q_B=\sum_{i=1}^n q_{i,B}=\frac{1}{(n+1)b}\left[na-n\alpha-\beta\sum_{i=1}^n\left(ne_{i,B}^2-\sum_{j\neq i}e_{j,B}^2\right)\right]. \tag{8}$$

The optimal efficiency level for this Cournot-Nash equilibrium before the EU-ETS is such that there are no explicit incentives for companies to invest in environment-friendly solutions, meaning that $e_{1,B}=\cdots=e_{n,B}=0$. As a consequence, the output reduces to

$$q_{i,B}=\frac{1}{(n+1)b}(a-\alpha) \quad \forall\, i=1,\ldots,n \;\text{ and }\; Q_B=\sum_{i=1}^n q_{i,B}=\frac{n}{(n+1)b}(a-\alpha). \tag{9}$$

On adding the optimal solutions into the profit function, the payoff equals to

$$\pi_{i,B}=\frac{1}{(n+1)^2b}(a-\alpha)^2 \quad \forall\, i=1,\ldots,n \tag{10}$$

is obtained. □

Enforcement of the EU-ETS, as discussed in the previous section, induces some change in the cost function and in the innovation incentives provided to aviation companies reflected in the result derived in Proposition 2.

Proposition 2 *In the Cournot-Nash equilibrium for the EU-ETS period, the payoff for the* i^{th} *airline company is equal to*

$$\pi_{i,E}=\frac{\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)^2}{(n+1)^2b}+\frac{\Delta\gamma}{n} \quad \forall\, i=1,\ldots,n;\;\; \Delta=(P_a\delta_a+P_m\delta_m+P_r\delta_r-P_m\delta_s) \tag{11}$$

Proof. In the second period, the reaction curve for the i^{th} airline operator ($i=1,\ldots,n$) given the maximization of (3) and reaction curves of all the other companies denoted by $q_{-i,E}=\sum_{j\neq i}q_{j,E}$ is

$$R_{q_{i,E}}(q_{-i,E})=\frac{1}{2b}\left(a-bq_{-i,E}-\alpha-\beta e_{i,E}^2-\frac{\Delta}{e_{i,E}}\right). \tag{12}$$

Recalling that $\Delta=\delta_m(P_m-P_r)+P_r$, the reaction curve is influenced by the EU-ETS through the rate of allowances purchased on the carbon market or the rate of allowances not surrendered to the European Commission. The equation below (13) describes the Cournot-Nash equilibrium output

$$q_{i,E} = \frac{1}{(n+1)b}\left[a - \alpha - \beta\left(ne_{i,E}^2 - \sum_{j\neq i} e_{j,E}^2\right) - \Delta\left(n\frac{1}{e_{i,E}} - \sum_{j\neq i}\frac{1}{e_{j,E}}\right)\right] \quad \forall\, i = 1,\ldots,n. \tag{13}$$

In addition, given the first order condition (FOC) and the homogeneity assumption, the optimal efficiency effort or green investment induced by the EU-ETS to reduce emissions is $e_{1,E} = \cdots = e_{n,E} = e_E = \sqrt[3]{\frac{\Delta}{2\beta}}$, which induces an output level equal to

$$q_{i,E} = \frac{1}{(n+1)b}\left(a - \alpha - \frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right) \quad \forall\, i = 1,\ldots,n \tag{14}$$

with

$$Q_E = \sum_{i=1}^{n} q_i^E = \frac{n}{(n+1)b}\left(a - \alpha - \frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right). \tag{15}$$

Finally, the payoff given the optimal Cournot output of the i^{th} company has value

$$\pi_{i,E} = \frac{\left(a - \alpha - \frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)^2}{(n+1)^2 b} + \frac{\Delta\gamma}{n} \tag{16}$$

□

Comparing this result with what was found for Proposition 1, potential EU-ETS effects on profits and on output are evident. Under the EU-ETS, the optimal quantity is reduced by $g_\Delta = \frac{3}{2}\sqrt[3]{2\Delta^2\beta}$. This means that the output is reduced by the unitary cost of the efficiency effort made by the firm β and by Δ, the variable which summarizes the cost of the EU-ETS. In the same way, the profit level is affected by these two components. However, Δ has a twofold effect. In addition to the negative effect of output and profit reduction, it creates positive effects on the profit function accordingly to the amount of free allowances (γ/n) assigned to the company. The overall effect of Δ depends on the magnitude of this component and on the amount of emissions allocated free of charge. Note that the profit in the EU-ETS period is higher than before if and only if

$$\frac{3n}{2}(2\Delta^2\beta)^{2/3} + (n+1)^2 b\Delta\gamma - 3n(a-\alpha)\sqrt[3]{2\Delta^2\beta} > 0.$$

To understand the effects of the EU-ETS on other market structure, a monopoly solution is also discussed. This additional step is useful for exploring how equilibria change before and after the EU-ETS if aviation companies decide to cooperate rather than compete, for example through a cartel. In this case, firms maximize the cumulative profit $\pi = \sum_{i=1}^{n} \pi_i$. The difference between the collusion solution and the best response solution treated in the first two Propositions is that in the former case the firms are aware that their profits depend on their total production. Conseguently, they will behave together as a monopolist in maximizing their profits.

Proposition 3 *The monopoly output for the aviation sector before and after the introduction of the ETS induces, respectively, profit levels*

$$\pi_{i,B} = \frac{(a-\alpha)^2}{4nb} \quad \textit{and} \quad \pi_{i,E} = \frac{\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)^2}{4nb} + \frac{\Delta\gamma}{n} \quad \forall\, i=1,\dots,n. \tag{17}$$

Proof. Under the assumption of a cartel (i.e. a monopoly), the maximization problem in the benchmark and in the EU-ETS period is, respectively

$$\max_{q_i, i=1,\dots,n} \pi_B = \max_{q_i, i=1,\dots,n} \sum_{i=1}^{n} \left[\left(a - b \sum_{i=1}^{n} q_{j,B} \right) q_{i,B} - (\alpha + \beta e_{i,B}^2) q_{i,B} \right] \tag{18}$$

and

$$\max_{q_i, i=1,\dots,n} \pi_E = \max_{q_i, i=1,\dots,n} \sum_{i=1}^{n} \left\{ \left(a - b \sum_{i=1}^{n} q_{j,E} \right) q_{i,E} - (\alpha + \beta e_{i,E}^2) q_{i,E} - \Delta \left[\frac{q_{i,E}}{e_{i,E}} - \gamma \left(\frac{q_{i,B}}{\sum_{j=1}^{n} q_{j,B}} \right) \right] \right\}. \tag{19}$$

Deriving first order conditions, optimal efficiency levels reach the already identified amounts, i.e. $e_{i,B} = 0$ and $e_{i,E} = \sqrt[3]{\frac{\Delta}{2\beta}}$. Moreover, the optimal monopoly output is, for every $i = 1, \dots, n$, in the two distinct period equal:

$$q_{i,B} = \frac{a-\alpha}{2nb} \quad \text{and} \quad q_{i,E} = \frac{1}{2nb}\left(a - \alpha - \frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right) \tag{20}$$

Then, the total industry outputs are $Q_B = \sum_{i=1}^{n} q_{i,B} = \frac{a-\alpha}{2b}$ and $Q_E = \frac{1}{2b}\left(a - \alpha - \frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)$ and profits associated with the two distinct cases are:

$$\pi_{i,B} = \frac{(a-\alpha)^2}{4nb} \quad \text{and} \quad \pi_{i,E} = \frac{\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)^2}{4nb} + \frac{\Delta\gamma}{n} \quad \forall i=1,\dots,n. \tag{21}$$

$\square$

Comparing Cournot and monopoly outputs for companies under the EU-ETS, it seems that the main differences do not depend on the introduction of the allowances system. This can be translated into the conclusion that the aviation market's structure is not influenced by the enforcement of this market-based instrument, even though outputs and profits are affected by the

EU-ETS. Given these two scenarios, since cartels are not sustainable in the long terms because companies have an incentive to deviate, this analysis will discuss the case of perfect collusion with one firm deviating. The profit obtained in the first and second period when cooperation is expected, but it is not achieved because of the deviation of the j^{th} firm, must be derived. In other words, the firm that decides to deviate from the cartel has to maximize its profit given that the remaining $n-1$ firms will still produce the monopoly output.

Proposition 4 *If $n-1$ firms agree on collusion, but the j^{th} deviates, then profit functions are, in the benchmark case*

$$\pi_{i,B} = \frac{(n+1)(a-\alpha)^2}{8bn^2} \quad \textit{and} \quad \pi_{j,B} = \frac{[(n+1)(a-\alpha)]^2}{16bn^2}$$

and in the EU-ETS period

$$\pi_{i,E} = \frac{(n+1)\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)^2}{8bn^2} + \frac{\gamma\Delta}{n} \quad \textit{and} \quad \pi_{j,E} = \frac{\left[(n+1)\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)\right]^2}{16bn^2} + \frac{\gamma\Delta}{n}.$$

Proof. The results illustrated in this proposition can be easily derived from first order conditions. Note that the optimal output for the j^{th} firm that does not collude in the two periods are, respectively

$$q_{j,B,D} = \frac{(n+1)(a-\alpha)}{4nb} \quad \text{and} \quad q_{j,E,D} = \frac{(n+1)\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)}{4nb}$$

such that the quantity produced by the industry in the benchmark and ETS periods will be

$$Q_B = q_{j,B} + \frac{(n-1)}{2nb}(a-\alpha) \quad \text{and} \quad Q_E = q_{j,E} + \frac{(n-1)}{2nb}\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right).$$

Finally, given optimal outputs, profits for the $n-1$ firms that collude are equal to

$$\pi_{i,B} = \frac{(n+1)(a-\alpha)^2}{8bn^2} \quad \text{and} \quad \pi_{i,E} = \frac{(n+1)\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)^2}{8bn^2}$$

and profits for the j^{th} that deviates are equal to

$$\pi_{j,B} = \frac{[(n+1)(a-\alpha)]^2}{16bn^2} + \frac{\gamma\Delta}{n} \quad \text{and} \quad \pi_{j,E} = \frac{\left[(n+1)\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)\right]^2}{16bn^2} + \frac{\gamma\Delta}{n}.$$

□

The main difference is the reduction of the profit of the company that decides to deviate from the collusion. The remaining $j-1$ operators still behave as a monopoly, in the sense that they are still part of a cartel. Thus, the deviation from the collusion is not profitable for all agents. Profits are lower than that in the monopoly case especially for the j^{th} firm that decides not to take part in the collusion. Hence, this strategy is dominated by the monopoly one.

3.1 Non-homogeneous firms

Propositions 1 and 2 can be extended by relaxing the homogeneity assumption and allowing, without loss of generality, there to be two distinct types $r = 1, 2$ of companies among the n characterizing the Cournot oligopoly. Specifically, there is a first group ($r = 1$) composed of $k \cdot n$ firms, with $k \in [0, 1]$, a homogeneous infra-group, while the remaining firms belong to the second group ($r = 2$). Profit functions in the two periods differ among groups given a specific structure of marginal costs. The latter depend on values of α_r and β_r. In detail, they are equal to

$$\begin{aligned}\pi_{i,B} &= \left(a - b\sum_{j=1}^{n} q_{j,B}\right) q_{i,B} - (\alpha_r + \beta_r e_{i,B}^2) q_{i,B} \\ \pi_{i,E} &= \left(a - b\sum_{j=1}^{n} q_{j,E}\right) q_{i,E} - (\alpha_r + \beta_r e_{i,E}^2) q_{i,E} - f(q_{i,E}, e_{i,E}, \mathbf{P}, \boldsymbol{\delta}).\end{aligned} \tag{22}$$

Thus, Proposition 1 can be extended by identifying profits associated with the first and second group

$$\begin{aligned}\pi_{i,B,1} &= \frac{1}{(n+1)^2 b}(a - \alpha_1 - n(1-k)(\alpha_1 - \alpha_2))^2 \quad \forall\, i = 1, \ldots, kn, r = 1 \text{ and} \\ \pi_{j,B,2} &= \frac{1}{(n+1)^2 b}(a - \alpha_2 - nk(\alpha_2 - \alpha_1))^2 \quad \forall\, j = 1, \ldots, (1-k)n, r = 2\end{aligned}$$

and Proposition 2 can be characterized to accommodate heterogeneity:

$$\pi_{i,E,1} = \frac{\left(a - \alpha_1 - \frac{3}{2}\sqrt[3]{2\Delta^2\beta_1} - n(1-k)(\alpha_1 + \frac{3}{2}\sqrt[3]{2\Delta^2\beta_1} - \alpha_2 - \frac{3}{2}\sqrt[3]{2\Delta^2\beta_2})\right)^2}{(n+1)^2 b} + \frac{a - \alpha_1 - n(1-k)(\alpha_1 - \alpha_2)}{n(a - k\alpha_1 - (1-k)\alpha_2)}\Delta\gamma$$

$$\pi_{j,E,2} = \frac{\left(a - \alpha_2 - \frac{3}{2}\sqrt[3]{2\Delta^2\beta_2} - nk(\alpha_2 + \frac{3}{2}\sqrt[3]{2\Delta^2\beta_2} - \alpha_1 - \frac{3}{2}\sqrt[3]{2\Delta^2\beta_1})\right)^2}{(n+1)^2 b} + \frac{a - \alpha_2 - nk(\alpha_2 - \alpha_1)}{n(a - k\alpha_1 - (1-k)\alpha_2)}\Delta\gamma$$

$\forall\, i = 1, \ldots, kn$ and$j = 1, \ldots, (1-k)n.$

Maximizing (22), the extension of Propositions 1 and 2 can be proved, given reaction curves and optimal outputs[8].

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[8] Reaction curves and associated optimal outputs in the benchmark period are respectively: $R_{q_{i,B,r}}(q_{-i,B}) =$

3.2 An empirical illustration: the effect of the EU-ETS on Italian carriers

For the purpose of obtaining practical conclusions and managerial insights, in this section we test the model's prediction for Cournot output, profit and innovative incentives at national level focusing on Italian carriers. As said, Italian carriers are encountering more difficulties than most of the other European countries airlines in adapting to the new regulatory framework. Apart from the well-known Alitalia case, other national carriers have gradually suffered an erosion of their market shares as a consequence of decreasing competitiveness in routes served. In 2015, there are only two airlines with an Air Operator Certificate issued by the ENAC, the Civil Aviation Authority of Italy, among the first 10 largest airlines in terms of total passengers operating in Italy. Considering the domestic market alone, the share of Italian carriers is larger, with five airlines in the first 10.

Moreover, Italian aviation GHG emissions are higher than the mean European GHG emissions (see Fig. 3).

The competitive position of Italian airline companies makes them a rather interesting case for analysing how the additional costs that firms must face to cope with the EU-ETS potentially affect market equilibrium and innovative efforts. In what follow, we therefore limit our analysis to Italian carriers (i.e. with an Air Operator Certificate issued by the ENAC). The almost total lack of complete and detailed data on single routes in terms of frequency of service, departure schedule, and associated efforts and costs imposes some simplification when applying the model. First, following recent contributions (Chin and Zhang, 2013) we use tonne/km emissions as a proxy for the quantity supplied by airlines to take the potential effect of the EU-ETS into account. Secondly, in considering only the Italian carriers, we cover only part of the market, since other airlines, those with certificates from other European authorities, are excluded. Finally, we implicitly consider individual airlines competing with all the others in the market. Actually, airlines directly compete only with those airlines offering flights on the same routes also taking into account airport substitutability[9]. Conversely, this implies that the number of airlines on single routes are generally limited: hence they are properly modeled via a Cournot oligopoly.

Following our theoretical model, we consider an inverse linear demand function

$$P(Q) = a - bQ$$

$\frac{1}{2b}\left(a - bq_{-i,B} - \alpha_r\right)$; $q_{i,B,1} = \frac{a-\alpha_1-n(1-k)(\alpha_1-\alpha_2)}{(n+1)b}$ $\forall\, i = 1, \dots, kn$ and $q_{j,B,2} = \frac{a-\alpha_2-kn(\alpha_2-\alpha_1)}{(n+1)b}$ $\forall\, j = 1, \dots, (1-k)n$. Moreover, reaction curves and associated optimal outputs in the ETS period are respectively: $R_{q_{i,E,r}}(q_{-i,E}) = \frac{1}{2b}\left(a - bq_{-i,E} - \alpha_r - \frac{3}{2}\sqrt[3]{2\Delta^2\beta_r}\right)$; $q_{i,E,1} = \frac{a-\alpha_1-\frac{3}{2}\sqrt[3]{2\Delta^2\beta_1}-n(1-k)(\alpha_1+\frac{3}{2}\sqrt[3]{2\Delta^2\beta_1}-\alpha_2-\frac{3}{2}\sqrt[3]{2\Delta^2\beta_2})}{(n+1)b}$ $\forall\, i = 1, \dots, kn$ and $q_{j,E,2} = \frac{a-\alpha_2-\frac{3}{2}\sqrt[3]{2\Delta^2\beta_2}-kn(\alpha_2+\frac{3}{2}\sqrt[3]{2\Delta^2\beta_2}-\alpha_1-\frac{3}{2}\sqrt[3]{2\Delta^2\beta_1})}{(n+1)b}$ $\forall\, j = 1, \dots, (1-k)n$.

[9] Competition authorities adopt the approach of the point-of-origin/point of destination pair approach ("O&D") to define relevant markets in air transport of passengers.

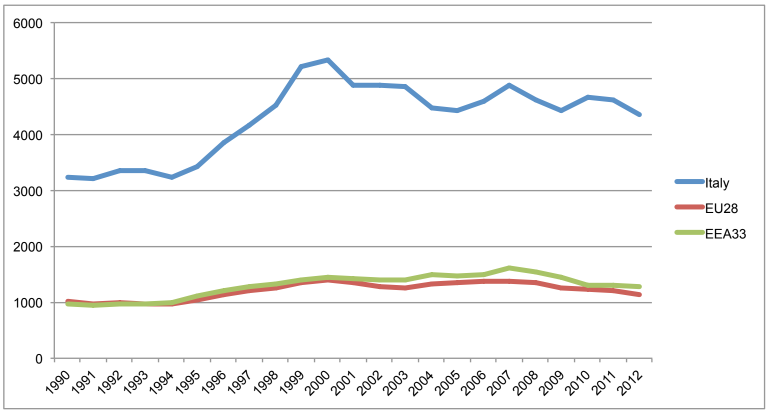

Figure 3: European28 and EEA33 mean historical emissions compared with the Italian one. Data from 1990 to 2012

characterizing the Italian market[10]. Moreover, to accommodate the more general framework of non homogeneous firms, we investigate national company types through a cluster analysis based on accountability data extracted from the Bureau van Dijk's AIDA database. The Italian aviation sector under EU-ETS proves, in fact, to be composed of two groups: one represented by the Italian Aviation company (Alitalia) and a second one grouping all the other companies. This is evident from the result of a hierarchical cluster analysis performed considering 2012 and 2013 data on verified emissions, earnings, EBITDA, and the free allowances received by the 10 airline companies. The cluster has been constructed by starting from the Euclidean distance matrix computed for standardized data and applying the Ward method. The latter ensures the realization of a hierarchy in which groups are characterized by a minimum with-in deviance but a maximum infra-group deviance. This satisfies the necessity to have, in each cluster, observations very similar to each other and, simultaneously, very different from those lying in the remaining groups. In detail, the dendrogram in Fig. 4 makes it possible to identify the two cited clusters representing the Italian airline operators.

Hence, we model company heterogeneity, accordingly to the model presented in Section 3.1, assigning the following parameter values: $\alpha_i = 0$ for $i = 1, \ldots, 10$, $k = \frac{1}{10} = 0.1$, $\beta_1 = 1$ (Alitalia), $\beta_i = \frac{1}{2}$ for $i = 2, \ldots, 10$. On the one hand we assume, for the sake of simplicity, constant and null marginal operating costs α_i. In this way we concentrate the attention on the

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[10] In this case we do not normalize the slope b to 1, differently from the approach followed by Barbot et al. (2014); Chin and Zhang (2013). Fixing $b = 1$, in fact, seems to be too unrealistic according to the discussion proposed in section 2.2 and in (Anger and Köhler, 2010). The assumption $b = 1$ will induce a loss of generality given a too high demand variation consequent on just a small price change.

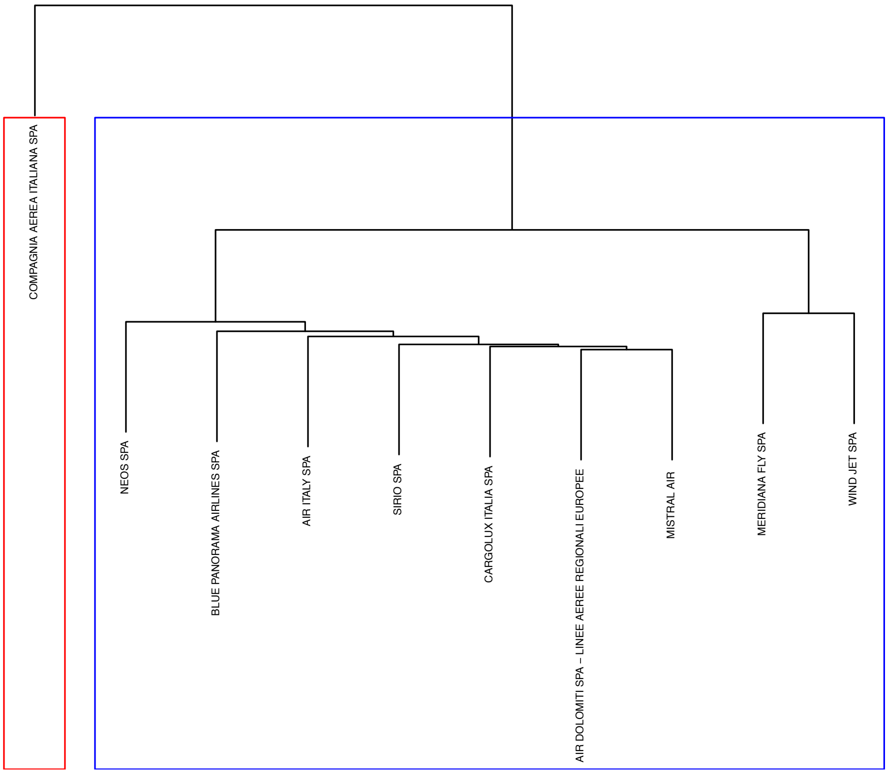

Figure 4: Dendrogram representing the hierarchical cluster analysis based on the Ward method and on the Euclidean distance matrix

main key factors associated with the introduction of the EU-ETS given our research aims. On the other hand, the quadratic costs, function of the abatement effort $\beta_i e_i^2$, partially following Barbot et al. (2014), are:

$$c(e_1) = e_1^2 \quad \text{and} \quad c(e_i) = \frac{e_i^2}{2} \;\; i = 2, \ldots, 10.$$

Hence, in the benchmark period there were 10 active aviation companies. Using the model described in this paper, in 2012, the maximization problem leads to the following Cournot output and profit:

$$q_{i,B} = \frac{a}{11 \cdot b} \;\text{ and }\; \pi_{i,B} = \frac{a^2}{121 \cdot b} \quad \forall\, i = 1, \ldots, 10.$$

Note that, in 2012, the verified emissions assumed to be the amount Q_B were equal to 3449656 tonnes of verified emissions[11]. Then, in 2014, the 10 firms registered under the EU-ETS (with Wind Jet in judicial composition with creditors) produce 2117003 tonnes of verified emissions. For this year the cap is set to be $\gamma = 0.95$, the mean market price for the selected year is 5.96 euros per tonne of CO_2, the percentage of allowances bought on the secondary market is $\delta_m = 0.3615$, and no allowances have been auctioned by the considered Italian companies $\delta_s = 0$, hence:

$$\pi_{i,E,1} = \frac{(a-3.15)^2}{121 \cdot b} + \frac{2.05}{10} \text{ with } i = 1 \text{ and } \pi_{j,E,2} = \frac{(a-9.01)^2}{121 \cdot b} + \frac{2.05}{10} \;\; \forall\, j = 2, \ldots, 10$$

and $Q_{E,1} = \frac{1}{11 \cdot b}(a - 3.15)$ and $Q_{E,2} = \frac{9}{11 \cdot b}(a - 9.01)$[12]. This application suggests that the profits of the two group airline operators are greater than the one in the benchmark period if and only if $a_1 > 1.646 - 3.937 \cdot b$ and $a_2 > 4.505 - 1.377 \cdot b$[13].

4 Conclusions

This paper has provided a new model with which to study the impact of the EU-ETS on aviation sector market equilibrium. By explicitly allowing for abatement efforts and innovation incentives in the cost function of airline companies, the results contribute to better understanding of the overall effects of the EU-ETS and thus support policy-making decisions. The price and the output equilibrium before and after enforcement of the EU-ETS are summarised in Table 1

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[11] With $Q_B = 3449656$, $\frac{a}{b}$ can be approximately equal to 3794621.6

[12] In 2014 the verified emissions for Alitalia were 1578058 and for all the other companies 538945. Then the intercept of the demand for the first and second group, i.e. a_1 and a_2, can be approximated respectively with the following values $a_1 = 17358638 \cdot b + 3.15$ and $a_2 = 592839.5 \cdot b + 9.01$.

[13] Thus with the values for a_1 and a_2 defined in the previous note these conditions reduce to almost $b \geq 0$

for the three different hypotheses on the market structure analysed, namely oligopoly (Cournot model) with homogeneity and heterogeneity firms, monopoly, and cartel deviation. As can be seen, two main factors influence airline profits when the EU-ETS is enforced: the share of allowances distributed free of charge (coefficient γ), and the abatement effort cost of the airline (β).

Table 1: Summary results on payoffs according to different competitive assumptions

Assumptions	Before EU-ETS	After EU-ETS
Cournot oligopoly	$\pi_{i,B} = \frac{1}{(n+1)^2 b}(a-\alpha)^2$	$\pi_{i,E} = \frac{\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)^2}{(n+1)^2 b} + \frac{\Delta\gamma}{n}$
Monopoly	$\pi_{i,B} = \frac{(a-\alpha)^2}{4nb}$	$\pi_{i,E} = \frac{\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)^2}{4nb} + \frac{\Delta\gamma}{n}$
Deviation of the j^{th} firm	$\pi_{i,B} = \frac{(n+1)(a-\alpha)^2}{8bn^2}$ $\pi_{j,B} = \frac{[(n+1)(a-\alpha)]^2}{16bn^2}$	$\pi_{i,E} = \frac{(n+1)\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)^2}{8bn^2} + \frac{\gamma\Delta}{n}$ $\pi_{j,E} = \frac{\left[(n+1)\left(a-\alpha-\frac{3}{2}\sqrt[3]{2\Delta^2\beta}\right)\right]^2}{16bn^2} + \frac{\gamma\Delta}{n}$

Referring to γ, profits are positively influenced by the quantity of free allowances received. This is quite intuitive as the more free allowances are distributed to firms, the less they have to buy permits from the market in order to cover their actual emissions if they suffer an allowances deficit. Referring to β, its value depends on the abatement effort, that is, any investment specifically aimed at reducing pollutant emissions. As a consequence, whenever it takes a positive value, air companies will incur higher operational costs and experience lower profits. The latter point is crucial because it contributes to explain the role of the incentives provided by the EU-ETS. The penalizing effect is the same for all the market structures analysed, but its extent is greater for those where competitive forces are stronger.

Nevertheless, it is worth noting that, even if one could expect lower profits due to greater abatement efforts, the overall effect remains uncertain because it is related to the magnitude of γ. From a policy point of view, the interaction between firm strategies to reduce GHG emissions and the decision about the share of allowances allocated free of charge plays an important role in reinforcing airlines' innovation incentives. Formally, the larger is the quota of permits granted for free, the lower is γ, depressing its positive contribution to airline profits.

As explained, the effect of γ and β is also related to the value of Δ, which takes into account several factors describing individual airlines' decisions about the total amount of allowances sold and/or bought, either on the secondary market or via auction; the number of permits that firms decide to sell and/or buy in each market; the level of allowances prices; the intensity of sanctions.

In particular, outcomes are strongly related to airlines' strategies in response to changes introduced by the EU-ETS and to how the scheme itself is designed (see Table 1).

From a different perspective, in terms of quantities supplied on the market, we register a negative effect on equilibrium quantities that depends only on the relationship between unitary abatement effort cost and airlines' strategies, but not on the share of free allowances assigned to single airline companies. This allows us to conclude that observed variations of equilibrium quantities reflect new opportunities and markets, as well as the endorsed abatement effort cost of airlines encouraged with the EU-ETS.

Collusive outcome exhibits different levels of equilibrium quantities and profits with respect to the oligopoly assumption. Interestingly, the main differences do not refer to the components discussed so far (β, γ, Δ), which still enter the quantity and profit functions in the same manner: they only relate to EU-ETS exogenous factors, such as the number of firms on the market and the demand elasticity.

Finally, our empirical application on Italian companies highlights the role of firms' heterogeneity as well as demand elasticity in market equilibria. Demand estimation for the aviation sector (a), demand elasticity (proportional to b), and conditions on model parameters (a, b) are central in determining airlines' profits under the EU-ETS compared to the benchmark period.

Our analysis also raises to some challenging model issues related to the difficulties inherent in modelling the aviation sector complexity, the lack of data on quantities effectively supplied by airlines on each routes served which limit the ability to characterize market competition, and the necessity to relax some model assumptions in order to to accommodate a dynamic analysis.

Thus, a very interesting inquiry would be to assess alternative designs of the EU-ETS scheme in terms of incentives, allowances and sanctions to compare the effects on competitiveness, efficiency level, profits and abatement effort. A dynamic modelisation with challenging policy implications could be introduced to allow for progressive changes in the emission cap as well as in the share of allowances granted for free. Such an extension, enriched by an optimizing routes perspective, seems quite promising to characterize the EU-ETS better.

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