The environmental costs of airports' aviation activities: a panel data econometric analysis of Italian airports

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Abstract

Aviation is a fast growing sector with increasing environmental concerns linked to aircrafts' emissions during airport operations (LTO cycle, taxing, etc.) and noise nuisance. It is recognized that such externalities should be internalized within the sector's costs and paid by agents operating in it. This paper is an attempt to tackle these issues, by analyzing the noise and emissions produced by the Italian airports during the period 1999-2008. We provide the methodology to compute the amount of pollution produced yearly by an airport and its instant average yearly level of noise. Two indices measuring the airport externalities levels, expressed as monetary social costs, are designed and computed. A panel data fixed effect econometric model is applied to a dataset covering information on airports' externalities, activities, ownership and fleet characteristics. We show that a 1% increase in airport's yearly movements yields a 1.018% increase in total externality costs, a 1% in aircraft's size (measured in MTOW) gives rise to a 1.251% increase in costs and a 1% increase in aircraft age brings a 0.443% increase in externality costs. Other factors affecting social costs are aircraft manufacturers (total costs are lower the higher the share of movements operated by Airbus and Boeing aircrafts), engine manufacturers (CFM, Pratt-Whitney and Rolls-Royce engines are more costly) and the fraction of freight movements. Our policy implications are that the tariff internalizing the total social costs is about Euro 150 per flight, while the tariff limiting only pollution costs is about Euro 50 and that reducing noise is about Euro 100.

KEYWORDS: Airport noise and pollution, factors affecting externalities, tariffs limiting social costs, fixed effect panel data econometric model.

CLASSIFICATION: Environmental Issues in Air Transport Industry; Air Transport Policy and Regulation; Airline Economics.

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1. Introduction

It is widely acknowledged that aviation is one of the fastest growing sector of the global economy: over the past 20 years the average annual growth rate was around 5% (Vespermann and Wald, 2011). In 2011, according to ICAO world passengers-kilometres increased by 6.5% (ICAO, 2012), with airlines of ICAO's 191 member states carrying about 2.7 billion passengers, with an increase of 5.6% over 2010. Forecasts on future growth rates vary between 5.3% (IATA, Airline Industry Forecasts, 2011-2015) and 7.5% (Airbus, 2012 Global Market Forecasts 2011-2031); hence, the growth rate is expected to be robust also in the future, following the development of the global economy. The expansion of aviation has raised concerns regarding its environmental impacts. Some recent estimates (Lee et al., 2009) show that the sector is responsible for about 3.5% of global green house gas, with a predicted increase to 15% by 2050 (IPCC, 1999). Environmental concerns are also linked with aircrafts' emissions during airport operations (e.g., landing and take-off cycle (LTO), taxing, etc.) and noise nuisance. These two externalities affect mainly the territory around airports (including population, animals, plants, crops, water, land, etc.) and, together with the green house gas externality, it is widely recognised that they should be internalized within the sector's costs and paid by agents operating in it (e.g., companies, users, etc.).[1] Efforts to integrate externalities measures in air transport policies have been implement both at the global (ICAO) and European level: evidence of them is provided in Section 2. While some estimates on the global externality produced by aviation are available (e.g., Vespermann and Wald, 2011), very few studies have tackled the issue of estimating the local externalities produced by this sector, i.e., the airports' local emissions and noise nuisance. Nevertheless, the concerns related to airports' activities may be very strong locally, as shown by the hot debates regarding projected airports' expansion plans.

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[1] Efforts to integrate externalities measures in air transport policies have been implement both at the global (ICAO) and European level. ICAO has been making a great effort, since 1970, to reduce: (1) the number of people affected by aircraft noise, (2) the impact of aircraft engine emissions on surface air quality and (3) the problems related to green-house emissions. At the European Union level, the Environmental Council is responsible for Directives related to emissions, while the European Aviation Safety Agency (EASA) deals with the regulation of aircraft noise levels in the vicinity of airports. The first Directive specifically relevant to local air quality at airports is 99/30/EC (receipted in Italy with the Legislative Decree n. 60/2002), which covers SO2, NO2 and NOx, PM10 and Pb1. We also mention the Directive 2008/50/EC, which sets standards and target dates for reducing concentrations of fine particles, and Directive 2008/101/EC adopted to provide for the inclusion of aviation activities in the European Emissions Trading Scheme (ETS). Regarding noise, Directives 2002/30 and 2002/49 establish common criteria for operating restrictions at Community airports, set the framework for airport noise management procedures and mandate that States must produce noise maps and noise action plans for airports with more than 50.000 movements per year. Moreover, Directive 2006/93/EC precludes the use in the territory of Member States of aircrafts that are not compliant with Chapter 3 of Volume I of Annex 16 to the Convention on International Civil Aviation (Chicago Convention). At the Italian level, the legislative framework regulating noise pollution is given by Law 447/95 and by Legislative Decree 31/10/97 which imposes for each civil airport the identification of noise abatement procedures and noise contours maps (to plan the land use management). Local authorities participate actively in the process, along with airport operators, environmental agencies, civil aviation authorities and air navigation service providers. Legislative Decrees 13/2005 and 194/2005 implement respectively EU Directives 2002/30 and 2002/49.

Hence, the goal of this paper is threefold: (1) to provide a general methodology for computing airport local externalities, (2) to investigate the factors affecting them and (3) to provide, as a policy implications, some estimates of the tariffs that should be imposed on airports to internalize the social costs.

We develop two indices in order to assess the impact of airports' aviation activities on the local environment, one regarding the yearly amount of pollution produced by aircrafts during their land-and-takeoff (LTO) cycle and one measuring the instant yearly average of noise created by an aircraft during a LTO cycle. Hence, the noise index represents the noise exposure of the people surrounding the airport in a given time instant. Both indices are in monetary values (Euro) yielding the social costs of airports' aviation activities during a year.[2] The two indices take as starting point in the computation method the aircraft/engine combination certification values, established according the ICAO Annex 16 (Vol. 1 and 2) and combine information gathered by several databases: IRCA (International Register of Civil Aircraft) for data on engines installed in different aircrafts, EASA (European Aviation Safety Agency), FAA (Federal Aviation Administration) for information on noise certification values, ICAO Engine Emission Databank for pollutants certification data, and OAG (Official Airline Guide) for aircraft movements in Italian airports over the period 1999-2008.

The noise and pollution indices are applied to a sample of 31 Italian airports representing about 90% of total annual aircraft movements to investigate the factors affecting their levels of externalities. We study empirically the determinants of the total social costs of airport pollution and noise produced by developing two models: (1) a airport model, where the determinants of externalities are some factors under control by the airport's management (e.g., the yearly number of aircraft movements, of freight movements, the share of low cost carriers (LCC), etc.) and (2) a general model where the determinants are also factors controlled by airlines (e.g., the aircraft's age, the aircraft and engine manufacturers, etc.). Empirical evidence on these two models is provided by applying to a fixed effect panel data econometric model. We also consider separately the social costs of pollution and of noise.

The estimated coefficients of the econometric models allow drawing some policy implications that may be relevant in the current debate of the environmental effects of aviation and in assessing the social impacts of airports' expansion plans on the surrounding population and land. Our aim is to provide some monetary estimates of the social costs of a further increase in airport's activity, or in expanding the aircraft size or in not updating the aircrafts technology. These estimates may be

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[2] Aspects related to vehicular traffic in proximity of airports and supporting activities for aviation (mostly passenger shuttle, catering service and supply) and airport infrastructure are not considered here for lack of data.

applied to airport charges to give to the aviation sector the necessary incentives toward an environmental sustainable development. Furthermore they may be considering as an estimate of the total costs (i.e., both private and social) of building a new runway.

The paper is organized as follow: in Section 2 we review the literature on airport environmental effects while in Section 3 we present two indices describing the amount of pollution and the level of noise produced by an airport, and the methodology to apply them to the available databases on aircrafts and engines certification data. In Section 4 we present the empirical models, in Section 5 the data set while in Section 6 we describe the econometric results. Section 7 presents the policy implications and Section 8 highlights the main conclusions of the paper.

2. Literature review

Our contribution is linked with some papers that have studied the environmental effects of airports' activities. Schipper (2004) analyses the impact of airports' operations on local and global air pollution (green house gases), on noise nuisance and on accident risk applied to a sample of routes linking some of the main European airports. Hence, he does not consider a national system but only a small sample of the sector's activities. The methodology regarding local air pollution is based on the impacts on human health with a life horizon, while the level of noise is computed through the hedonic price method. The latter is based on case studies. While regarding emissions we share some methodological aspects (i.e., some of the pollutants emitted during the LTO cycle) and differ for not considering the global effects (we focus on local impacts), our approach is different in relation to noise. We do not consider hedonic prices, since they are extremely case-dependent, and our aim is to analyze a national system. However, Schipper's estimate on per aircraft movement monetary noise costs is adopted here to convert the level of noise measured in dB into euro values.

Lu and Morrell (2006) estimate the environmental costs of noise and pollution in a small sample of European airports (Heathrow, Gatwick, Stansted, Schipol and Maastricht). The index adopted to compute pollution costs is similar to the one adopted here, but the methodology of application is different since they only consider the movements of some aircraft's categories and not the effective airport's aviation activities as in our contribution. As in Schipper, they adopt the hedonic price method to estimate the social costs of noise. Morrell and Lu (2007) apply the approach developed in their previous contribution to compare the environmental costs of two models of aviation activities: hub-hub versus hub by-pass networks. Again a small sample of 8 world airports is considered. Lu (2009) considers the impact on airlines' demand of introducing emission charges, by adopting a methodology similar to Lu and Morrell (2006) and applying it to a small sample of European routes. Givoni and Rietveld (2010) study the environmental costs of using linking cities when it is possible to use aircrafts of different sizes: narrow-bodies and wide-bodies. The index adopted to compute pollution costs is similar to ours, but its application is different since it considers only few aircraft's types (and without any engine characterization); regarding noise, the index is similar, but it not consider engine difference and it is not transformed into monetary values. Lu (2011) presents a study on the environmental costs of airport operation in a single case (Taiwan Taoyuan international) using an approach similar to Lu and Morrell (2006).

All the above contributions present some drawbacks: the hedonic price method is based on observed property values and their characteristics among which the vicinity to the airport is of interest. Coefficient estimates of the variable for airport vicinity may be biased for omitting some relevant characteristics, for instance due to lacking of information. Case studies are specific and difficult to generalise. However, they do not discriminate by engine manufacturer. Concerning local emissions, previous contributions focus on the different pollutants emitted by aircrafts during airport's operations (e.g., nitrogen oxide NOx, sulphur dioxide SO2, etc.) and compute the costs of emissions by taking into account the amount of fuel burnt by an aircraft during the LTO cycle. Fuel is then converted into pollutants through certified conversion factors and then multiplied by some estimates of unit social costs of pollutants. However, again, they do not discriminate by engine. Furthermore, previous contributions concentrate only on few representative aircrafts. These limitations make difficult to understand which are the environmental implications of different technological settings: for instance, it is not possible to quantity the gap in social costs if the same aircraft model is operated which different engine configurations; or which is the impact of technical progress for environmental costs. This paper is an attempt to tackle these issues, by analyzing the noise and emissions produced by all the aviation activities performed in a national airport system over a period of time.

3. How to measure airport's noise and pollution

The environmental impacts of aviation in airports are mainly linked with pollution and noise. Here we present the methodology to estimate the social costs of airport pollution and noise. Our aim is to present an approach that is applied to the aircraft fleets operating in the different airports, taking into account their different characteristics. Hence, we will propose first two indices measuring the amount of pollution and noise produced by a specific aircraft and then apply these measures to the number of movements observed in a specific airport during a year. In doing so we implement a methodology which is based on several databases, each one adding relevant information about the amount of pollution and the level of noise produced by an aircraft during a

LTO cycle. Last, we convert these measures, that are expressed in quantities of pollutants and in decibels, into monetary values.

3.1 The social costs of pollution in airport operations

Airports are responsible for pollution emitted at the local level. Pollution emitted during the cruise is mainly contributing to global warming and can be attributed to airlines. As stated by ICAO Annex 16, Volume 2, local air pollution is given by the amount of gases produced by aircrafts during their LTO cycle. The latter, following ICAO standards, is split into four stages: take–off (lasting 0.7 min), climb (up to 3000 ft, lasting 2.2 min), approach (from 3000 ft to landing, lasting 4 min), and idle (when the aircraft is taxing or standing on the ground with engines-on). The 3000 ft (approximately 915 m) boundary is the standard set by the ICAO for the average height of the mixing zone, the layer of the earth atmosphere where chemical reactions of pollutants can ultimately affect ground level pollutant concentrations (EPA, 1999). ICAO sets limits for the production of engine emissions of unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_X). The limits for CO and HC refers to the ratio of the emitted mass to the thrust value (g/kN) and varies depending on the engine's initial date of production. Regarding NO_X, ICAO certification requirements are more complex. In addition to the abovementioned ratio, they refer also to the pressure ratio between inlet and outlet of the compressor and are distinguished by considering both the production date of the first engine in the series and the date of manufacture of the engine under investigation, to take account of possible engine upgrades. In addition, the Annex 16 original reference values for certificated pollutants were reviewed by the CAEP and periodically modified by introducing more stringent criteria.[3] Based on the values measured during certification, the manufacturer must indicate the emission factors (or more precisely the Emission Indices, EI), which are calculated from the volume of fuel consumed (mass of pollutant in gr/mass of fuel in kg). The emission factors are recorded by ICAO in the Engine Emissions Databank, managed by the UK Civil Aviation Administration and is available on the Internet.

In addition to the production of CO, HC and NO_X, following earlier studies (Dings et al. 2003, Schipper 2004, Lu and Morrell 2006), we also consider the production of carbon dioxide (CO_2), sulphur dioxide (SO_2) and respirable particulate matter (PM_{10}).

In order to build a complete set of the above pollutants emitted during a LTO cycle by each type of aircraft currently operating in commercial aviation, we implement a step-by-step methodology, merging information coming from several databases.

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[3] Revisions to the norm are identified by the name of the ICAO committee in charge so that the original one has been updated with CAEP 2 which in turn evolved into CAEP 4 and subsequently into CAEP 6 (CAEP 8 is yet to be determined). New limits have been set assuming a percentage reduction on the previous values.

The starting point of the procedure is the aviation operation in a specific airport, which is obtained from OAG. The latter provide information about each flight operating in an airport during a year, and indicates the type of aircraft used by the airline operating that flight. Hence, the information are on a single flight, non for a route. However, OAG does not provide information about the engines installed on the aircraft that is operating a specific flight, but only the maximum-take-off weight (MTOW).

In order to obtain the amount of pollutants emitted, which is function of the engine type installed in a specific aircraft, our second step of the procedure is the matching of the OAG information with the ICAO Engine Emissions Databank, which provides the certification information for each engine type (but not for each possible aircraft/engine combination). It specifies, for each phase of the LTO cycle, the HC, CO, NO_X emission factors and the fuel consumption.[4] For each LTO phase, emission factors have been multiplied by their time length and fuel consumption, to obtain the amount of HC, CO and NO_X produced. These per-phase amounts are then aggregated to obtain the amount of HC, CO and NO_X produced by each engine type during each departure or arrival operation.

Regarding the amount of CO_2, SO_2 and PM_{10} produced at the airport level, the computation is performed as follow: the fuel burnt by each engine type during the LTO cycle is multiplied by a stoichiometric coefficient (Dings et al.. 2003. Sutkus et al.. 2001), that is equal to 3.157 kilograms per kilogram of fuel burnt for CO2, to 0.8 for SO_2 (grams per kilogram of fuel burnt) and to 0.2 for PM_{10} (grams per kilogram of fuel burnt).

The last step of the procedure is the matching between the aircraft model operating a flight (obtained from OAG) and the engine type. To this purpose, we consider the International Register of Civil Aircraft, IRCA, providing detailed statistics on the types of engines installed on aircrafts. For example, Table 1 shows the frequency of each engine type installed on the Airbus A320. The highest percentage of currently operating A320 has the V2527-A5, produced by the International Aero Engine (IAE) manufacturer, while the second percentage is given by A320 with the CFM 56-5A3, produced by CFM International. The amount of different pollutants emitted during the LTO are then obtained as the weighted average of the different engine types associated to each aircraft, using the IRCA frequency as weight.[5]

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[4] The ICAO LTO cycle model is divided into four phases: (1) takeoff, lasting 0.7 minutes, climb-out, lasting 2.2 minutes, approach, lasting 4 minutes and idle, which is divided into two sub-phases: taxi-in, lasting 7 minutes and taxi-out, lasting 19 minutes. To obtain the emissions for each engine type, the take-off, climb-out and taxi-out phases are assigned to departure operations, while the approach and taxi-in phases are attributed to the arrival operations.

[5] Information regarding aircrafts not available in IRCA database have been obtained as average value for the various engine options from the European Aviation Safety Agency EASA database.

Table 1: IRCA engine statistics for Airbus A320.

Engine model	IRCA frequency
CFM 56-5 A1	6.9%
CFM 56-5A3	12.3%
CFM56-5B/4P	1.3%
CFM 56-5B4	6.0%
CFM 56-5B4/2P	5.0%
CFM 56-5B4/P	7.3%
V2500-A1	8.0%
V2527-A5	48.5%
V2527E-A5	4.7%
Total	100.0%

Source: IRCA

The final outcome of this procedure is a engine-weighted average value for each of the six pollutants considered in this contribution emitted during the LTO cycle by each aircraft. In order to compute the total quantity of pollutant *p* produced by aircraft *i* during the LTO cycle, and defined as Q^i_p , we considered the following equation:

$$Q^i_p = n^i_j \times \left(\sum_{f=1}^{4} E_{pjf} \times d_f \times Fc_{jf} \right)$$

where n^i_j is the number of type-*j* engine installed on aircraft *i*, E_{pjf} is the type-*j* engine emission factor (*E*) of pollutant *p* (in kilograms) during phase *f* of the LTO cycle, d_f is the time-duration of the phase *f* and Fc_{jf} is the type-*j* engine fuel consumption (measured in kg/sec) during phase *f*. For instance, Table 2 presents the pollutants emitted by aircrafts A320, A321 and Boeing 737 (in 7 different model specifications) during the departure session of the LTO cycle. Each value is kilograms and is the total amount produced during all departure phases. It is evident that there is a quite relevant heterogeneity among these commonly used aircrafts.

Table 2: Engine-weighted average pollutants (kg), A320, A321, B737, departures.

Aircraft	HC	CO	NO_X	CO_2	PM_{10}	SO_2
Airbus A320	0,304	4,600	9,031	1897,544	0,120	0,481
Airbus A321	0,691	5,955	13,569	2223,442	0,141	0,563
Boeing 737-200	2,083	7,437	6,519	2113,807	0,135	0,539
Boeing 737-300	0,538	8,756	6,337	1818,882	0,115	0,461
Boeing 737-400	0,439	8,076	7,376	1952,482	0,124	0,495
Boeing 737-500	0,450	8,136	7,326	1944,997	0,123	0,493
Boeing 737-600	0,682	5,843	6,670	1663,070	0,105	0,421
Boeing 737-700	0,626	5,627	8,350	1831,835	0,116	0,464
Boeing 737-800	0,554	5,192	9,636	1933,948	0,123	0,490

Source: computation on ICAO and IRCA databases

Table 3 presents the same values but for the arrival stages. In addition to the above mentioned model heterogeneity it is evident that emissions are lower during arrivals than departures.

Table 3: Engine-weighted average pollutants (kg), A320, A321, B737, arrivals.

Aircraft	HC	CO	NO_X	CO_2	PM_{10}	SO_2
Airbus A320	0,167	2,168	1,861	798,132	0,051	0,202
Airbus A321	0,404	3,130	2,367	903,636	0,057	0,229
Boeing 737-200	0,898	3,494	1,396	882,989	0,056	0,224
Boeing 737-300	0,205	3,640	1,656	773,699	0,049	0,196
Boeing 737-400	0,168	3,367	1,852	822,674	0,052	0,208
Boeing 737-500	0,172	3,390	1,844	820,124	0,052	0,208
Boeing 737-600	0,254	2,483	1,719	705,211	0,045	0,179
Boeing 737-700	0,234	2,340	1,936	766,332	0,049	0,194
Boeing 737-800	0,207	2,126	2,128	800,127	0,051	0,203

Source: computation on ICAO and IRCA databases

In order to obtain the amount of pollutants produced by an airport during a year, we multiply Q_p^i by the number of flights operated by aircraft *i* in airport *h*, defined as m_h^i. Hence, the following equation gives the total amount of pollutant *p* (kg) produced in airport *h* yearly:

$$P_{ph} = m_h^i \times Q_p^i$$

To obtain the social costs of emissions and to aggregate different amounts of pollutants in a single index, we considered the estimated social costs of each pollutant, defined as C_p, provided by Dings et al. (2003). [6] The Local Air Pollution (LAP) index, i.e., the social costs of yearly emissions in airport *h*, is then obtained as the sum of the kg produced of each pollutant *p* weighted for the relative cost of damage C_p:

$$LAP_h = \sum_{p=1}^{6} C_p \times P_{ph}$$

3.2 The social costs of noise in airport operations

The social costs of noise produced yearly by airports are computed using a similar procedure adopted for emissions. The level of noise produced by each engine/aircraft combination is obtained from information available in the European Aviation Safety Agency (EASA) and in the Federal Aviation Administration (FAA) databases. These sources provide data on the vast majority of

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[6] Dings et al. (2003) estimate a social cost of 4 Euro/kg for HC and 9 Euro/kg for NOx. Carbon monoxide (CO) emissions from aircraft operations do not appear to result in substantial health effects and therefore a cost estimate for emission of this gas is assumed equal to 0 Euro/kg (see also Givoni and Rietveld, 2010), as well as CO_2 emissions during the LTO cycle, which are therefore equal to 0 as social costs. The social cost of a kilogram of PM_{10} is equal to Euro 150 while the unit social cost of a kilogram of SO_2 produced during the LTO cycle is equal to Euro 6.

aircrafts such as the manufacturer, model, maximum takeoff weight, engine type and number and noise certification data. OAG records reporting the airports movements operated by a specific aircraft model have been therefore linked with EASA and FAA databases. This process has been carried out in two steps. In the first one, we matched the aircrafts according to their model name. In the second one, among the associations resulting from the first step, we selected only those having similar takeoff weights.[7] The same procedure presented before for emissions gives rise to the computed noise levels shown in the A320, A321 and Boeing 737 examples reported in Table 4.

Table 4: Average noise levels (dB), A320, A321, B737.

Aircraft	Approach _Level	Lateral _Level	Flyover_Level
Airbus A320	95,1	92,5	85,4
Airbus A321	96,4	96,4	88,8
Boeing 737-200	96,4	96,7	90,7
Boeing 737-300	99,0	90,3	85,0
Boeing 737-400	99,3	91,8	86,8
Boeing 737-500	97,9	89,7	81,7
Boeing 737-600	95,7	91,2	84,8
Boeing 737-700	96,0	92,8	85,0
Boeing 737-800	95,9	93,6	84,1

Source: computation on EASA/FAA and IRCA databases

The amount of noise produced by an aircraft during a LTO cycle is measured in three different points, located nearby the airport. They provide the Effective Perceived Noise Level (EPNdB) for take-off and landing operations. The EPNL is an indicator obtained from measurements of sound pressure level for 24 third-octave bands through a process that takes into account spectral irregularities and duration of the event. To evaluate landing operations the measurement point, called “Approach”, is placed under the landing trajectory at 2.000 meters from the threshold. To evaluate take-off operations there are two reference noise measurement points. The first one, called “Flyover” is placed under the take-off trajectory at 6.500 meters from the start of roll; the second, called “Lateral”, is located at 450 meters to the right or left of the runway (several measuring stations parallel to the runway must be deployed).[8] Table shows that the highest noise levels are measured at Approach and Lateral points, while lower levels are registered at

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[7] In order to take into account for possible heterogeneity in MTOW information we consider a range of +/- 3% in the MTOW value. This implies that a aircraft classified with the same model type in the OAG and EASA/FAA databases is not considered in the computation if the MTOW reported in the EASA/FAA databases is outside the +/-3% MTOW range. This aircraft is indicated in the EASA/FAA databases but it is not considered for weighting the noise computation of the aircraft registered in the OAG database.

[8] ICAO noise regulation imposes limits at each point that vary with the weight of the aircraft. For the “Flyover” point also the number of engines is considered, allowing a four-engine aircraft to be noisier than a two-engine ones. Originally jet and turboprop aircrafts with MTOW larger than 5.700 kilograms were classified in two groups of certification corresponding to two chapters of Annex 16. Chapter 2 (with higher levels for older and noisier technologies) and Chapter 3 (with lower levels). In March 2002 the rule was revised and a new chapter, Chapter 4, has been added. Since January 2006 the new standard imposes the reduction by 10 EPNdB of the aggregated value of the levels for all the measuring points compared to that of Chapter 3.

Flyover, and that there is a relevant heterogeneity among aircrafts, given that an increase of 3 dB represents a double increase in the level of noise (A320 in approach has a EPNL equal to 95.1, while B737-300 has 99, implying more than double noise exposure).

The next step in the noise computation procedure is the transformation of EPNL noise levels into the Sound Exposure Level (SEL). The latter is the most common metric in the calculation of noise maps, since it expresses the sound energy produced by an acoustic event. Because there is not a direct relation between the two metrics (EPNL is strongly dependent on the noise spectrum and the event duration, and consequently on the measurement point), the Integrated Noise Model (INM) has been adopted to reproduce certification tests calculating both EPNL and SEL for a large set of aircrafts at each measurement point (also reproducing the required standard weather conditions). We have considered four aircraft categories: wide-body (WB), narrow-body (NB), regional jet (RJ) and propeller powered (PP), identifying an average difference between EPNL and SEL to be used in the calculation. The results are presented in the Table 5. It shows that SEL values are always lower for all aircraft categories. Larger differences are observed for propeller powered aircrafts and for wide-body ones, in all measurement points. These average differences for each aircraft category are then used as conversion factors for any specific aircraft model.

Table 5: Average difference EPNL/SEL (dB) for aircraft categories

Aircraft categories	Approach	Flyover	Lateral
PP	5	3	4
RJ	3.75	2	1.75
NB	3.75	2.25	2.25
WB	4.25	3.25	2.75

Source: Computations on EASA/FAA and IRCA databases

SEL values at each measurement point *q* (i.e., approach, lateral and flyover) are then employed to compute an average noise exposure index (over the three measurement points) for aircraft *i*, labeled as ANE^i, and given by the following expression:

$$ANE^i = 10 \times log \times \left(\frac{1}{3} \times \sum_{q=1}^{3} ANE_q^i\right)$$

where ANE^i is the energetic mean of the dB values at the reference points ANE_q^i.[9] We need an estimate of the social costs of noise exposure. Hence, as a first step we consider as a reference

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[9] Since we are working with acoustic variables expressed in dB, we have to remind that they are logarithms and algebraic sum or average has no physical meaning.

social costs of an aircraft movement the average estimate provided by Schipper (2004), and equal to Euro 325.[10] This social cost corresponds to a noise level of 95.2dB. Hence, given that a decrease/increase of 3dB corresponds to a half/double level of noise exposure, each ANE^i is converted into Euro through the following expression:

$$MANE^i = \begin{cases} 0.5^{\frac{95.3-ANE^i}{3}} \times 325 & if \quad ANE^i < 95.3 \\ 2^{\frac{ANE^i-95.3}{3}} \times 325 & if \quad ANE^i > 95.3 \end{cases}$$

where $MANE^i$ is the monetary value of the average noise exposure of a movement operated by aircraft i in a given airport. Last, since we need a yearly estimate of social noise costs at airport h, the latter is given by summing over the year all the movements operated in airport h by aircraft I, and then by summing over all aircrafts. If we define $MANE^h$ as the yearly social costs of noise of airport h, this is given by:

$$MANE_h = \sum_{i=1}^{I} \sum_{m=1}^{M} MANE_m^i$$

where m represents the number of flights operated by aircraft i in airport h during a specific year, and I the total number of aircrafts operating in the same airport during the same period.

4. An econometric model on determinants of airports externalities

In this Section we present an econometric model to investigate which factors may affect the costs of externalities produced by airports. Given the feature of airports' activities, where aircrafts' operations are the result of both airport and airlines managers' decisions, we divide the analysis in two approaches:

a. airport model;
b. general aviation model.

In the airport model we focus only on factors under control by airport's managers that may affect the externalities costs. Among the available information we analyze in this case the effects of the yearly number of aircraft traffic movements (ATM), of the aircraft size (expressed in terms of MTOW), the share of movements dedicated to freights (FREIGHT), and the presence of low cost

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[10] Schipper (2004) gives an estimate of Euro 281 of the noise costs per aircraft movement at an airport. The estimate is for year 1995 and has been inflated using the OECD deflator.

carriers (LCC). The last variable aims to capture whether LCCs have an effect on externalities costs, given that they use always the same type of aircraft and that they are relatively young actors declaring to be environmental friendly. The presence of LCCs is captured by the share of movements operated by Ryanair (RYAN) and easyJet (EASY), which are the two most important LCC in the Italian market. Last, we consider the impact of airport's ownership to study whether public airports are more environmental friendly than private ones (which may be profit maximizers and, hence, not willing to internalize social costs). The latter is given by a dummy variable, PRIV, equal to 1 if the majority of airport's shares is controlled by private subjects.

The general aviation model investigates the impacts of factors under control of both airports and airlines managers. This means that in addition to the above mentioned variables, we take also into account the aircraft's age (AGE) and the aircraft manufacturer (given by the share of movements operated by a Boeing aircraft – BOEING, and by the share of movements operated by a Airbus aircraft – AIRBUS). Hence, the baseline aircraft manufacturer is given by aircrafts realized by all other manufacturers (i.e., Embraer, ATR, Fokker, etc.). Furthermore, we include in the analysis the engine manufacturer, through the share of flights operated with a CFM International engine (CFM), with a IAE engine (IAE), a Pratt&Whitney engine (PW), a General Electric engine (GE) and a Rolls-Royce engine (RR). The baseline engine manufacturer is then given by all the other companies (i.e., Allison Engine Company, KKBM, etc.).

The available information to study the sign, significance and magnitude of these factors is a panel data set. Hence we apply a panel data fixed effect econometric model. Fixed effects capture airport latent heterogeneity, i.e., factors that are time-invariant and not captured by the available data (e.g., the management ability, the long-term relationships with some airlines, etc.). The assumption of fixed effects will be tested both against the null hypothesis of a pooled econometric model (i.e., without considering that information vary across periods and airports) and against the null of a random effect panel data model. The former test is performed through a F-statistics, the latter through the well known Hausman test.

We consider logarithmic transformation for the total externality costs, annual aircraft movements, aircrafts' size and age. Hence the estimated coefficients regarding these variables are elasticities, and may provide relevant estimates for designing incentives for airports and airlines to reduce the amount of pollution and noise at the local level.

In the airport approach the econometric model is as follows:

$$\log TEC_{ht} = \alpha_0 + \alpha_h + \beta_1 \log ATM_{ht} + \beta_2 \log MTOW_{ht} + \beta_3 RYAN_{ht} + \beta_4 EASY_{ht} + \\ + \beta_5 FREIGHT_{ht} + \delta_1 PRIV_{ht} + \mu TIME + \varepsilon_{ht}, \qquad (1)$$

where TEC_{ht} is the total externality costs of airport h in year t, α_h is airport h fixed effect, $TIME$ is a discrete variable starting from 1 and ending with 10 (we have 10 years) capturing the technological progress effect on the dependent variable, and ε_{ht} is the error term, which is assumed to be white noise. In the general approach the econometric model is instead the following one:

$$\log TEC_{ht} = \alpha_0 + \alpha_h + \beta_1 \log ATM_{ht} + \beta_2 \log MTOW_{ht} + \beta_3 \tag{2}$$

Models (1)-(2) are also investigated using as dependent variables, separately, log LAP_{ht} and log $MANE_{ht}$. Hence we can also identify the separated effects of the explanatory variables on pollution social costs and on noise social costs. The latter are useful to obtain different externality-type tariffs that may be adopted by policy makers to provide incentives toward either greener fleets or less noisy ones.

5. The data

We study a data set composed by 31 Italian airports for the period 1999-2008. These airports cover about 90% of total annual aircrafts operations in Italy; the sample includes the two major Italian airports, Rome Fiumicino and Milan Malpensa, with more than 20 million passengers, and all the other major airports: Milan Linate, Venice, Milan-Bergamo, Naples, Catania, etc. The list of all airports is shown in the Appendix.

Table 6 presents the descriptive statistics on all the variables included in the econometric models (1)-(2), and their meaning. During the period 1999-2008 on average an Italian airport has created yearly a social costs of externalities equal to about 5.5 million Euro, of which about 1.7 million Euro regarding pollution and about 3.8 million Euro due to noise levels. The lowest social costs are equal to only about 9 thousands Euro, while the maximum social costs amount to about 56 million Euro. The representative airport has about 37 thousands aircraft movements, with a total *MTOW* over a year equal to about 3.7 million, and an average aircraft size per movement (MTOW/ATM) of about 57 tonnes. The average fleet age in the representative airport is almost 18 years, while only 16% of the airports in the sample have private ownership. Ryanair flights are on average (with a maximum of 100% flights in some airports), easyJet ones are only 1% but with a maximum of 18% in one airport (Milan Malpensa). Flights dedicated to freights are only 1% but there are airports with 100% of freight flights. Flights operated with Airbus aircrafts are 12%, while those operated with Boeing aircrafts are 54%. The share of flights with aircrafts equipped with

CFM International engines are 38% of the total in the representative airport, while those with Pratt&Whitney engines are 44%, with IAE engines only 2%, with General Electric engines 5% and with Rolls-Royce engines 5%.

Table 6: Descriptive statistics of variables included in the analysis

Variable	Mean	St. Dev.	Min	Max	Description
TEC	5,462,688	10,288,563	8,852.37	55,821,969	Euro
LAP	1,714,314	3,264,705	458.73	18,685,561	Euro
MANE	3,748,374	7,029,481	7,203.09	37,136,408	Euro
ATM	37,475.99	60,846.51	42	337,986	Number
MTOW	2,468,498	4,758,271	3,768	27,763,039	Tonnes
MTOW/ATM	56.98	16.62	21.63	157.53	Tonnes
AGE	17.98	2.43	6.32	29	Years
PRIV	0.16	0.37	0.00	1	Majority private
RYAN	0.15	0.26	0.00	1	Share of Ryanair mov.
EASY	0.01	0.03	0.00	0.18	Share of easyJet mov.
FREIGHT	0.01	0.09	0.00	1	Share of freighter mov.
AIRBUS	0.12	0.13	0.00	0.59	Share of Airbus mov.
BOEING	0.54	0.24	0.00	1	Share of Boeing mov.
CFM	0.38	0.26	0.00	1	Share of mov. with CFM engine
IAE	0.02	0.03	0.00	0.12	Share of mov. with IAE engine
PW	0.44	0.26	0.00	1	Share of mov. with PW engine
GE	0.05	0.08	0.00	0.97	Share of mov. with GE engine
RR	0.04	0.07	0.00	0.55	Share of mov. with RR engine

Table 7 displays the Kendall correlation index among all the variables. It is interesting to notice that negative correlation index for total externality costs (*TEC*) are found with the share of Ryanair flights (*RYAN*), the share of flights operated with Boeing aircrafts (*BOEING*) and with aircrafts with Pratt&Whitney engines (*PW*). Interestingly, aircrafts' age (*AGE*) is negative correlated with *RYAN* and *EASY*, confirming that LCCs have aircrafts relatively younger than other carries. Correlation is particularly high between total externality costs (*TEC*) and movements (*ATM*), and between *TEC* and *MTOW*.

Table 7: Kendall correlation indices

	TEC	MANE	LAP	ATM	AGE	RYAN	EASY	PRIV	FREIGHT	AIRBUS	BOEING	CFM	IAE	PW	GE	RR	MTOW
TEC	1	0.98	0.95	0.90	0.14	-0.25	0.29	0.24	0.13	0.49	-0.03	0.03	0.54	-0.11	0.37	0.37	0.95
MANE		1	0.93	0.91	0.14	-0.25	0.29	0.23	0.13	0.48	-0.04	0.02	0.54	-0.10	0.38	0.36	0.93
LAP			1	0.87	0.14	-0.24	0.30	0.25	0.12	0.52	0.00	0.06	0.55	-0.12	0.36	0.38	0.97
ATM				1	0.11	-0.26	0.28	0.22	0.10	0.47	-0.12	-0.01	0.52	-0.09	0.41	0.35	0.89
AGE					1	-0.48	-0.05	0.09	-0.07	0.16	0.15	-0.23	0.21	0.27	-0.12	0.16	0.14
RYAN						1	-0.03	-0.14	0.05	-0.19	0.12	0.33	-0.35	-0.24	-0.03	-0.18	-0.24
EASY							1	0.27	-0.09	0.31	-0.01	0.22	0.22	-0.24	0.25	0.22	0.30
PRIV								1	0.07	0.22	0.07	0.08	0.12	-0.13	0.10	0.13	0.25
FREIGHT									1	0.04	0.09	0.07	0.09	-0.14	0.17	-0.01	0.12
AIRBUS										1	-0.04	0.23	0.47	-0.18	0.18	0.25	0.52
BOEING											1	0.32	0.03	-0.10	-0.21	-0.01	-0.02
CFM												1	-0.02	-0.63	-0.05	0.01	0.06
IAE													1	0.02	0.20	0.31	0.54
PW														1	-0.15	-0.09	-0.13
GE															1	0.17	0.37
RR																1	0.37
MTOW																	1

Figures 1-3 show some scatter diagrams regarding total externality costs and most of our explanatory variables (clearly, we have excluded the dummy *PRIV* and the discrete variable *TIME*). In Figure 1 the top left panel shows the relation between total externality costs and aircraft movements, which is clearly positive, as well as the top right panel presenting the relation between costs and aircraft size. The bottom left panel displays the relation between total costs and aircraft age: it is evident that airports have fleets with age concentrated between 12 and 22 years, and that there is a relevant dispersion. The bottom right panel shows the relation between costs and freight: it is evident a relevant dispersion among airports, since many of those with a small percentage of freight flights have a variability in *TEC*.

Figure 1: Scatter diagrams, *TEC, ATM, MTOW, AGE* and *FREIGHT*

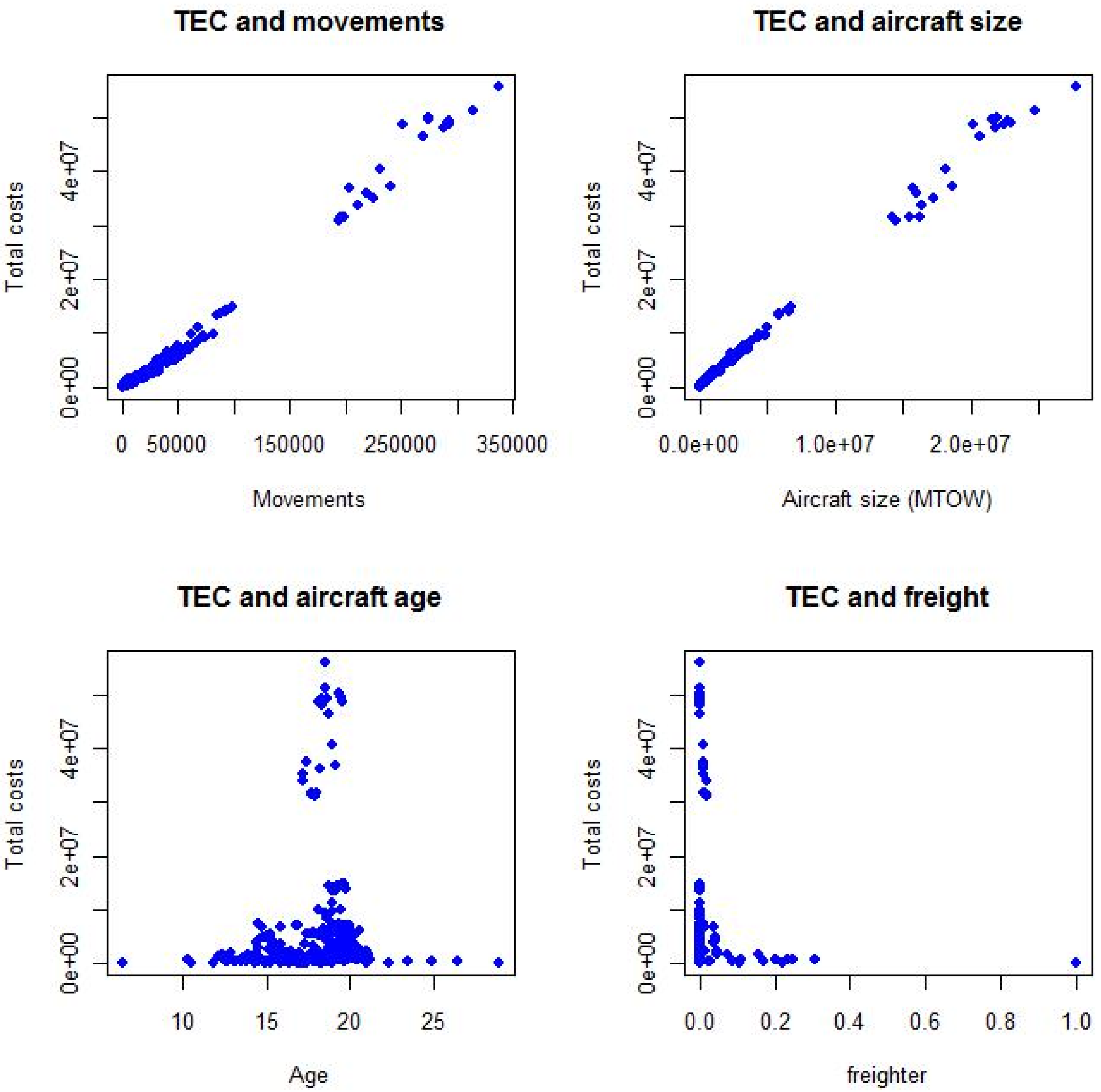


Figure 2 presents the scatter diagrams between total costs and *easyJet*, *Ryanair*, *Airbus* and *Boeing*. By inspection, in all panel there is a rather high variability, with the moderate exception of *Ryanair*, which is concentrated in low *TEC* values.

Figure 2: Scatter diagrams, *TEC*, *EASY*, *RYAN*, *AIRBUS* and *BOEING*

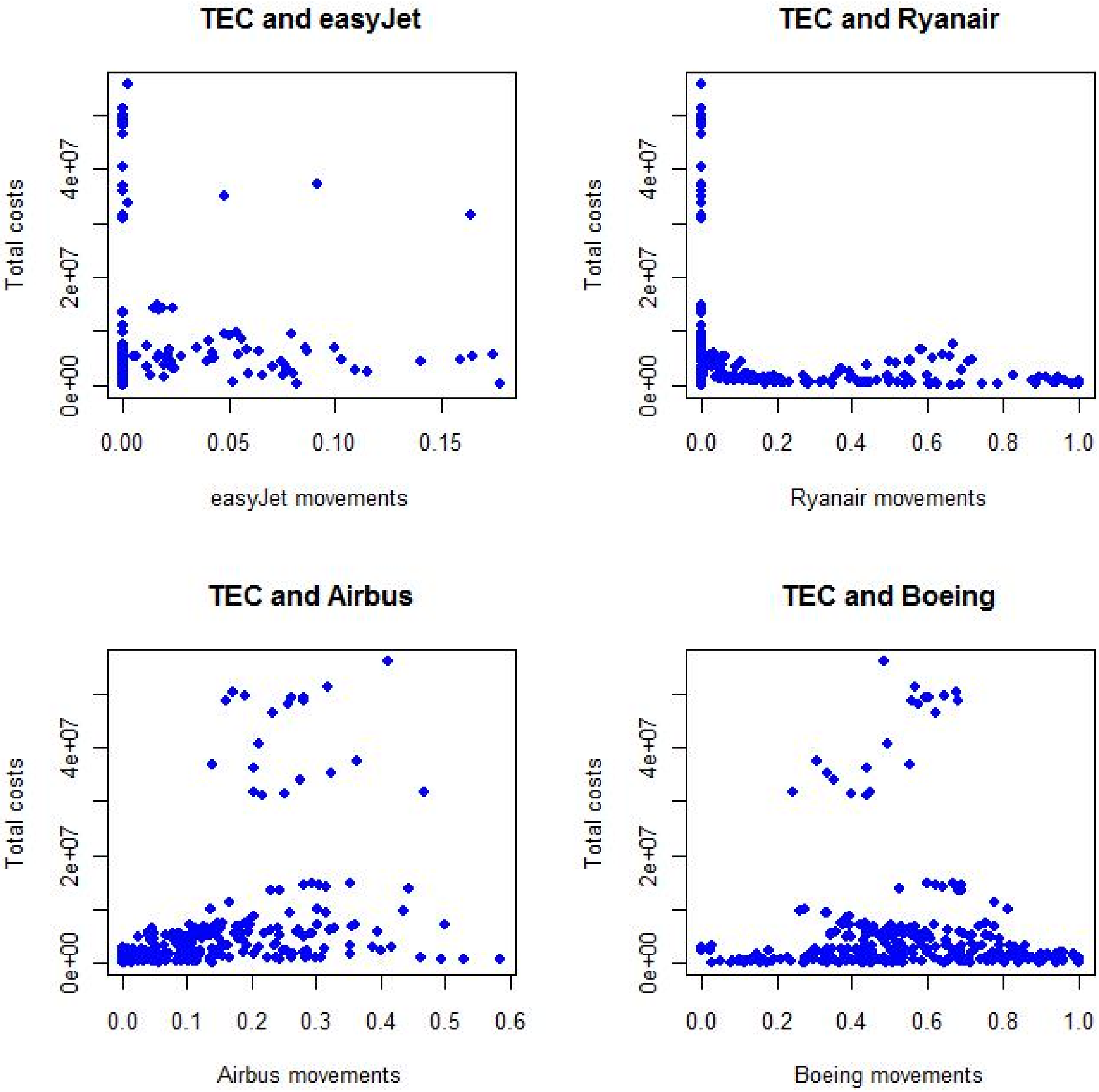
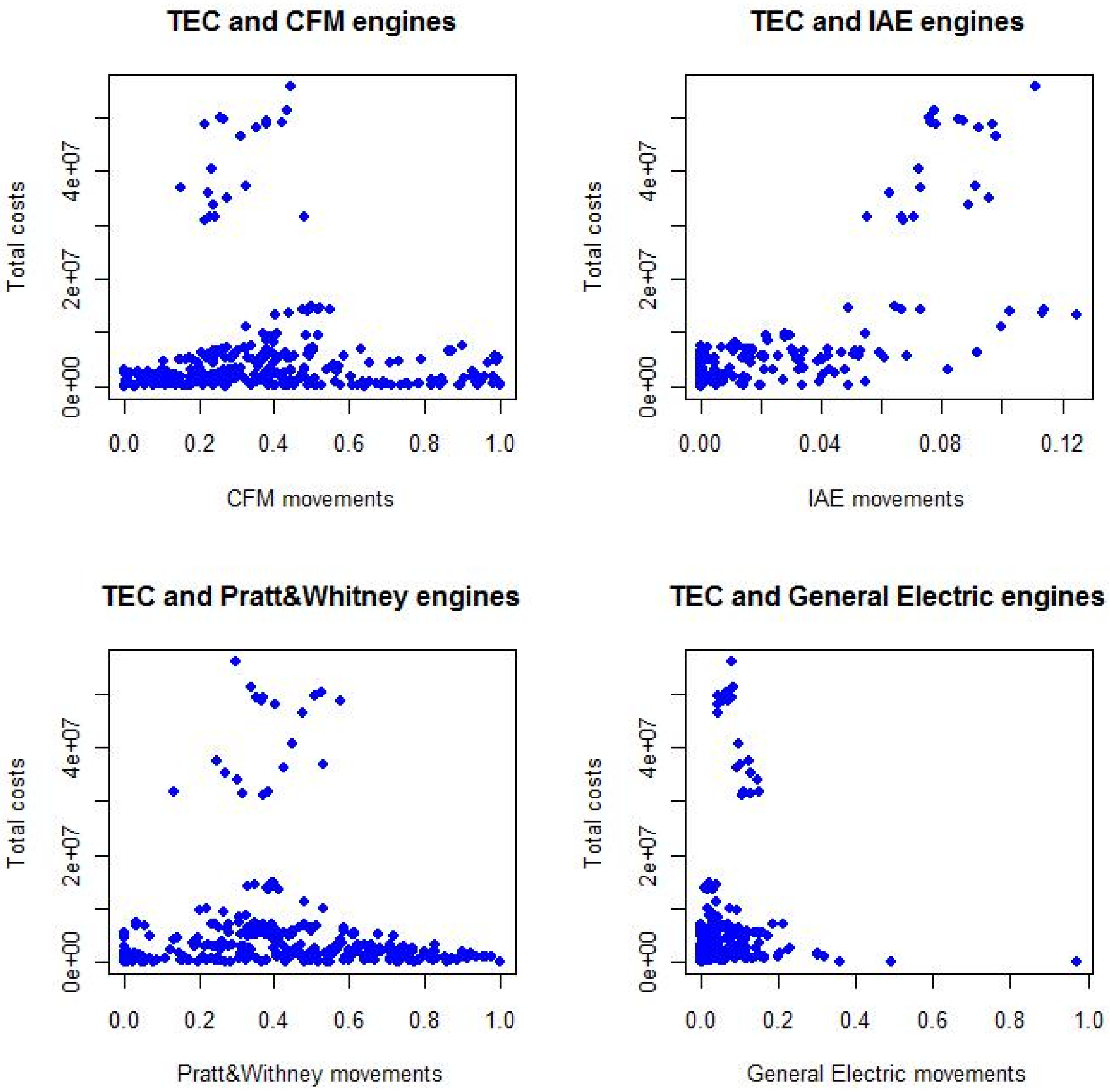


Figure 3 displays the scatter diagrams between total externality costs and 4 engine manufacturers (to save space we choose not to present the relation between *TEC* and Rolls-Royce engines, but the trend is similar). In all cases there is an important observed variability.

Figure 3: Scatter diagrams, *TEC*, *CFM*, *IAE*, *PW* and *GE* engines


TEC and CFM engines

TEC and IAE engines

TEC and Pratt&Whitney engines

TEC and General Electric engines

6. Econometric results

The effects of the explanatory variables in the airport approach estimated with the econometric model for panel data with fixed effect are shown in Table 8. It shows the coefficient estimates for all the airport model variables under three different dependent variable specifications: (1) total externality costs (*TEC*), (2) pollution costs (*LAP*) and (3) noise costs (*MANE*). Regarding the global environmental impact of airport activities, the regression with *TEC* as dependent variable has a positive and highly statistically significant coefficient for the aircraft movements. Being both *TEC* and *ATM* expressed in logarithms, the 1.02 estimated coefficient implies that a 1% increase in annual aircraft movements yields a 1.02% increase in total externality costs. Similarly, we get a elasticity estimate for the impact of aircraft size on total costs: the estimated coefficient for *MTOW_ATM* is 0.94, and it is highly statistically significant. Hence, a 1% increase in aircraft size gives rise to a 0.94% increase in total environmental costs. *Ryanair* has no effect on *TEC*, since the estimated coefficient is not statistically significant, while *easyJet* has a negative impact on total costs: the coefficient is equal to 0.57 and it is statistically significant. However, these coefficients are not elasticities, since the explanatory variables are not in logarithms. As expected, freight flights increase total environmental costs: the estimated coefficient for *FREIGHT* is equal to 0.21 and it is statistically significant. There is no estimated ownership effect: the coefficient of *PRIV* is negative but not statistically significant, while there is a interesting positive effect of technical progress, since the estimated coefficient of *TIME* is negative and statistically significant.

Table 8: Econometric results, airport model

	Dependent Variable					
	TEC		*LAP*		*MANE*	
Indep. Variables	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
ATM	1.02***	0.02	1.17***	0.04	0.98***	0.02
MTOW_ATM	0.94***	0.03	1.09***	0.07	0.90***	0.04
RYAN	0.02	0.04	-0.07	0.09	0.03	0.06
EASY	-0.57**	0.22	0.10	0.47	-0.75***	0.28
FREIGHT	0.21**	0.09	0.50**	0.20	0.13	0.12
PRIV	-0.03	0.03	0.02	0.07	-0.05	0.04
TIME	-0.02***	0.002	-0.02***	0.005	-0.02***	0.003
R^2	0.97		0.90		0.95	
Observations	310		310		310	

Legend: "***" = 1% significance, "**" = 5% significance, "*" = 10% significance

The estimates related to the airport model when we focus only on pollution costs are similar. Again, aircraft movements and aircraft size have a positive and significant effect on *LAP*: the former elasticity is +1.17%, while the latter is +1.09%. Both *Ryanair* and *easyJet* have no effect on pollution costs, while freight flights have a positive and statistically significant impact. There is no private ownership effect while technical progress is reducing airport pollution costs. The results for noise costs are similar regarding aircraft movements and aircraft size (even if the elasticities are lower being equal to +0.98% and +0.90%), *easyJet* has a negative impact on noise costs (while *Ryanair* has no effect), and, as expected freight flights do not produce higher noise costs than passengers ones. In all regressions the goodness of fit, given by the index R^2, is high.

Table 9 presents the econometric results for the general model, where both airports and airlines managers choices are taken into account. First per discuss the results regarding the total externality costs. The estimated coefficient for aircraft movements is positive and statistically significant: it implies a +1.02% elasticity in *ATM*, i.e., the total costs increase by this percentage if annual aircraft movements rise by 1%. The estimated elasticity for aircraft size (*MTOW_ATM*) is positive as well, statistically significant and of greater magnitude than that for movements: +1.25%. In the general model there is no *easyJet* effect, differently from the airport model where it has a negative impact on *TEC*, as well as *Ryanair*: the two estimated coefficients are not statistically significant. Again there is no airport ownership effect: the estimated coefficient for *PRIV* is not statistically significant. Interestingly, there is a positive and statistically significant estimated coefficient for the variable *AGE*, representing the average age of the fleet operating in Italian airports: since it is expressed in logarithms it is a elasticity and implies that a 1% increase in aircraft's age leads to a 0.44% increase in total externality costs. Freight flights have no effects on *TEC* (the estimated coefficient is not statistically significant), while there is evidence of an interesting negative effect on environmental costs of both Airbus and Boeing aircrafts. The estimated coefficient for *AIRBUS* is equal to -1.23, that for *BOEING* is -0.73. Hence, these two aircraft manufacturers are more environmental friendly than others, since airports with higher shares of flights operated by *Airbus* or *Boeing* have lower total externality costs. Among these two manufacturers, *Airbus* has the larger effect.

The last set of results confirms the presence of an engine effect on airport environmental costs, and provides some evidence on the different engine manufacturers impacts. Aircrafts equipped with CFM International engines have a negative effect on total costs: the CFM estimated coefficient is positive (0.74) and highly statistically significant. Similarly for aircrafts with Pratt&Whitney engines: however, the estimated coefficient (0.54) has a smaller magnitude, implying a lower effect than CFM International. A positive, statistically significant coefficient is estimated also for Rolls-Royce, but with the smallest magnitude (0.16). The other engine manufacturers (i.e., General Electric and IAE) have no effects: their estimated coefficients are not statistically significant. There is a positive impact of technical progress: the estimated coefficient for the variable *TIME* is negative (0.01) and statistically significant.

The second analysis performed with the general model is related to pollution costs. The estimated elasticity for aircraft movements (*ATM*) is equal to +1.13%, and it is highly statistically significant. Interestingly, the estimated elasticity for the aircraft size (*MTOW_ATM*) is statistically significant, positive but much smaller than for total costs: a 1% increase in aircraft size gives rise to only +0.49% in pollution costs (in comparison to a +1.25% increase in total costs). This implies that a large majority of the impact of aircraft size on total environmental costs is due to the noise effect rather than to the production of pollutants.

Table 9: Econometrics results, General model

	Dependent Variable

	TEC		*LAP*		*MANE*	
Indep. Variables	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
ATM	1.02***	0.01	1.13***	0.02	1.00***	0.02
MTOW_ATM	1.25***	0.07	0.49***	0.11	1.45***	0.09
RYAN	0.02	0.05	0.08	0.08	0.004	0.06
EASY	-0.08	0.18	0.41	0.29	-0.13	0.24
PRIV	0.02	0.03	-0.06	0.04	0.001	0.03
AGE	0.44***	0.06	0.47***	0.10	0.59***	0.08
FREIGHT	-0.10	0.09	0.66***	0.15	-0.31**	0.13
AIRBUS	-1.23***	0.14	0.33	0.22	-1.85***	0.18
BOEING	-0.73***	0.10	0.72	0.16	1.21***	0.14
CFM	0.74***	0.09	0.09	0.15	1.03***	0.12
IAE	0.41	0.36	1.11*	0.56	0.42	0.48
PW	0.54***	0.07	0.17	0.12	0.68***	0.10
GE	0.001	0.09	-1.31***	0.15	0.30**	0.12
RR	0.16*	0.10	0.20	0.15	0.12	0.13
TIME	-0.01***	0.002	-0.01***	0.005	-0.02***	0.003
R^2	0.98		0.97		0.97	
Observations	310		310		310	

Legend: "***" = 1% significance, "**" = 5% significance, "*" = 10% significance

Again, *Ryanair*, *easyJet* and private ownership have no effects on pollution costs, as well as total costs: their coefficients are not statistically significant. The average aircraft age of the fleet operating in the airport has a significant and positive estimated elasticity, equal to +0.47%: this implies that a 1% increase in aircraft age has a +0.47% increase in airport pollution costs. Freight flights have a positive impact on pollution costs: the estimated coefficient for the variable *FREIGHT* is positive (0.66) and statistically significant. This confirms a general impression that freight flights highly contribute to airports' pollution. It is interesting to note that, differently from total costs, aircrafts produced by Airbus and Boeing have no effects on pollutant costs. Hence these two important aircraft manufacturers do not differentiate themselves from other manufacturers in terms of pollutants emitted by aircrafts during the LTO cycle. Moreover, there is again a engine manufacturer effect, but opposite of that identified for total externality costs. CFM International, Pratt&Whitney and Rolls-Royce engines have no effects on airports pollution costs, while they positively affect total costs; on the contrary, IAE engines do not affect total costs but they have a positive and statically significant impact on pollution costs (the estimated coefficient of the variable *IAE* is equal to 1.11). General Electric engines have instead no effects on total costs but a relevant negative and statistically significant effect on pollution costs: the estimated coefficient for GE is equal to -1.31. Again there is positive impact of technical progress.

The last set of econometric results regard the general model and noise costs. Aircraft movements (*ATM*) have a positive and statistically significant elasticity, equal to +1%. Aircraft size (*MTOW_ATM*) has a significant and very high elasticity on noise costs: a +1% in aircraft size gives rise to a +1.45% in noise costs. This implies that larger aircrafts are more noisy than smaller ones, but also that their size effect is more than proportional. There is no evidence of an impact of LCCs and of private ownership airports on noise costs. Aircrafts' age has a positive and significant elasticity, equal to +0.59%. Interestingly, freight flights have a negative and significant effect on noise costs: this would imply that freight flights are less noisy than passengers ones. However, we do not take into account in this contribution that many freight flights operate at nights and so they should receive a 10dB penalty. This is left for future extension.

We find evidence of an interesting difference regarding noise costs between the two most important aircraft manufacturers: Airbus has a negative effect on noise costs, since the estimated coefficient is negative (-1.85) and significant. On the contrary, Boeing has a positive effect on noise costs: its estimated coefficient is positive (1.21) and significant. However this negative effect on noise costs for Boeing is more than compensated by lower pollution costs, since the estimated effect of Boeing on total environmental costs is negative and significant. Regarding engine manufacturers, CFM International, Pratt&Whitney and General Electric have a positive effect on noise costs, while IAE and Rolls-Royce have no effects. Again there is evidence of a technical progress since noise costs are lower over time. The goodness of fit of the models is rather high, as shown by the R^2 index.

In order to check for the robustness of our results some model mis-specification tests have been performed. The econometric analysis is based on a fixed effect panel data model, but the latter may not be correctly specified. The alternatives are the Pooled OLS model, where no fixed effects are taken into account so that there is no individual latent heterogeneity and the random effect model, where individual effects are random. Hence, we perform for each investigated model (i.e., Airport and General, total externality costs (total costs), pollution costs (*LAP* costs) and noise costs (*MANE* costs) two tests: the first test compares the fixed effect model and the Pooled OLS one and the null hypothesis H_0 is that the latter is the true model. The test is based on a *F*-statistic, and the null is rejected if the *P*-value is lower than 0.05. The second test is the well known Hausman test, comparing the fixed effect and the random effect models and the null hypothesis is that the latter is true. The Hausman test is based on a χ^2-statistics and the null is reject if the *P*-value is lower than 0.05. Table 10 shows the results for the mis-specification tests.

Table 10: Model mis-specification tests

	Fixed *vs* Pooled			**Fixed *vs* Random (Hausman)**		
Model	*F*	*P*-value	H_0: Pooled	χ^2	*P*-value	H_0: Random
Total costs – Airport	5.82***	0.000	Rejected	18.28**	0.011	Rejected
Total costs – General	2.97***	0.000	Rejected	20.46	0.160	Not Rejected
LAP costs - Airport	2.16***	0.001	Rejected	22.06***	0.003	Rejected
LAP costs - General	4.36***	0.001	Rejected	79.02***	0.000	Rejected
MANE costs - Airport	6.31***	0.000	Rejected	15.18**	0.034	Rejected
MANE costs - General	2.66***	0.000	Rejected	28.35**	0.020	Rejected

In all models the null hypothesis H_0 is rejected: this implies that the fixed effect panel data model is correct and that the results presented in Tables 8-9 are robust to model's mis-specification. However there is an exception: the null cannot be rejected in the model Total costs – General when the Hausman test is performed. This implies that the model specification should be a random effect model. Hence, we investigated for the total externality costs general model the Swamy-Arora specification of the random effect model. The result are shown in Table 11, showing that the only two main differences between the fixed effect and the random effect model are in the significance of the *FREIGHT* and *IAE* variables. The former is negative and significant in the random effect model (while is not significant in the fixed effect one); the latter is positive in the random effect model (as in the fixed effect one), but it is now significant.

Table 11: TEC General model estimates with Swamy-Arora random effect model

	Dependent Variable *TEC*	
Indep. Variables	Coeff.	S.E.
Intercept	-1.22***	0.24
ATM	0.99***	0.01
MTOW_ATM	1.28***	0.06
RYAN	-0.01	0.04
EASY	-0.02	0.17
PRIV	-0.02	0.02
AGE	0.38***	0.06
FREIGHT	-0.21***	0.07
AIRBUS	-1.23***	0.10
BOEING	-0.74***	0.07
CFM	0.77***	0.08
IAE	0.78***	0.27
PW	0.56***	0.06
GE	-0.05	0.08
RR	0.15*	0.08
TIME	-0.01***	0.002
R^2	0.99	
Observations	310	

Legend: "***" = 1% significance,
** = 5% significance, "*" = 10% signif.

7. Policy implications

The results obtained with the econometric analysis identify the factors affecting airports' externality costs but also provide the base for designing some aviation policies yielding incentives to airports' and airlines' managers towards more environmental friendly choices. The policies may be effective since they are linked to airport charges, that may include prizes and penalties related to the factors affecting externalities costs. Among these factors, the empirical analysis yields two airport charges designs: (1) using the elasticity estimates, it is possible to compute the social environmental costs of some additional aviation activities in airports, e.g., an additional flight; (2) using the sign of the factors that significantly affect the externalities costs it is possible to model prizes and penalties in presence of activities connected to these factor, e.g., flights with engine of some manufacturers.

First we derive the policy implication on airport charges using the estimated elasticities. In the total externality costs – general model, the elasticity for aircraft movements is +1.018% (in Table 9 rounded to 1.02). This implies that a +1% in yearly movements generates a +1.018 in total environmental costs. The annual average movements in airports of the sample is 37,475.99 movements, so that a +1% corresponds to 374.76 additional movements. The average total externality costs in the airports of the sample is Euro 5,462,688, so that a +1.018 is equal to Euro 55,610.16. By dividing the latter for the 374.76 additional movements we get the per-flight tariff that should be added to any airport movement, which is equal to Euro 148.38.

The same procedure can be applied to design a tariff not on flights but on aircraft size, measured in MTOW. The estimated elasticity is +1.251 (rounded to 1.25 in Table 9). The average MTOW for movement is equal to 56.98 tonnes, so that a +1% is 0.5698 tonnes and so the additional costs of an extra MTOW on a flight (i.e., a higher aircraft size) corresponds to Euro 68,338.23. By dividing it for 0.5698 tonnes we get the tariff that should be imposed annually on the average MTOW per flight, equal to Euro 119,933.7. Regarding age the estimated elasticity is 0.443. The average fleet age is 17.98 years; hence a +1% in age is 0.1798 years. The latter, since its elasticity is 0.443, gives rise to an increase of Euro 24,199.71 in total externality costs. By dividing the latter for 0.1798 we get Euro 134,629.3, which is that annual tariff per age of the average fleet age. Table 12 reports these tariffs and presents the charges (computed by applying the same procedure and using the different elasticities) for the pollution costs general model and for the noise costs general model. It is interesting to underline that tariffs based on noise costs should be consistently higher than that based on pollution costs.

Table 12: Airports charges providing incentives to environmental friendly management

	Annual airport charges per extra base variable (Euro)		
Base variable	Total costs	Pollution costs	Noise costs
Flights	148.39	51.55	99.92
Aircraft size (MTOW/flight)	119,933.70	14,892.69	95,321.06
Fleet average age	134,629.30	44,729.35	123,659.40

The second policy implications is related to a prize and penalty airport charge model. When considering total costs, the factors reducing them (excluding those where elasticity estimates are available) are flights operated with aircrafts manufactured by Airbus and Boeing: hence prizes in terms of lower airport charges should be granted to airlines using these aircrafts. On the contrary, factors increasing externality costs are aircrafts with engines manufactured by CFM International, Pratt&Whitney and Rolls-Royce: in these cases penalty in terms of higher airport charged should be imposed. If the policy focus only on pollution costs prizes are linked to aircrafts with General Electric engines, while penalties are related to freight flights, and those with aircraft equipped with

IAE engines. If the goal is to limit noise costs, prizes are connected to flights with Airbus and Boeing aircrafts while penalties should be imposed to flights with aircrafts equipped with CFM International, Pratt&Whitney and General Electric engines.

8. Conclusions

In this contribution we study the factors that may affect the environmental social costs produced by airports in their aviation activities, namely pollution and noise costs. The aim is to investigate whether some characteristics of airports and airlines choices do yield an increase in social costs. We build two indices to measure pollution and noise costs produced by an airport annually, taking into account, differently from previous contribution, the whole set of aircraft movements and the pollutants emitted and the noise produced by different combinations aircrafts/engines. Considering engines is indeed essential since the same aircraft model has different environmental effects due to the type of engines installed. The pollutants and noise levels are converted in monetary social costs and are then computed for a sample of 31 Italian airports, for the period 1999-2008.

We present two models investigating the determinants of airports' environmental costs: a airport model – where only activities under control (partially or totally) by airports' managers are taken into account, or some exogenous airports' characteristics – and a general aviation model where in addition to the factors included in the airport model also variables controlled by airlines' managers are included. We apply a fixed effect panel data econometrics model.

We provide evidence that a 1% increase in airport's yearly movements yields a 1.018% increase in total externality costs, a 1% in aircraft's size (measured in MTOW) gives rise to a 1.251% increase in costs and a 1% increase in aircraft age brings a 0.443% increase in externality costs. Other factors affecting social costs are aircraft manufacturers (total costs are lower the higher the share of movements operated by Airbus and Boeing aircrafts), engine manufacturers (CFM, Pratt-Whitney and Rolls-Royce engines are more costly) and the fraction of freight movements. Our policy implications are that the tariff internalizing the total social costs is about Euro 150 per flight, while the tariff limiting only pollution costs is about Euro 50 and that reducing noise is about Euro 100. We also design a prize/penalty scheme where tariffs may be lower/higher according to some aircraft and engine manufacturers identities and to freight flights.

The analysis can be extended to consider penalties in noise costs for night flights and interactions between aircrafts and engine manufacturer, and to include airline fixed effects. This is left for future research.

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Appendix

Table A1, List of Italian airports in the sample

Airport	Code	Airport	Code
Alghero	AHO	Milan Malpensa	MXP
Ancona	AOI	Naples	NAP
Bari	BRI	Olbia	OLB
Bergamo (Milan)	BGY	Palermo	PMO
Bologna	BLQ	Pescara	PSR
Brescia	VBS	Pisa	PSA
Brindisi	BDS	Reggio Calabria	REG
Cagliari	CAG	Rimini	RMI
Catania	CTA	Rome Ciampino	CIA
Crotone	CRV	Rome Fiumicino	FCO
Florence	FLR	Turin	TRN
Forlì	FRL	Treviso	TSF
Genoa	GOA	Trieste	TRS
Lamezia Terme	SUF	Venice	VCE
Lampedusa	LMP	Verona	VRN
Milan Linate	LIN		