Determinants of airports' environmental effects [*]

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Abstract

Aviation is a fast growing sector with increasing environmental concerns linked to aircraft emissions at airports and noise nuisance. This paper investigates the factors affecting the annual environmental effects produced by a national aviation system. The environmental effects are computed using certification data for each aircraft-engine combination. Moreover, we also take into account for the amount of environmental effects that is internalized at the airport, mainly through noise regulation. We study a dataset covering information on Italian airports during the period 1999-2008. We show that a 1% increase in airport's yearly movements yields a 1.05% increase in environmental effects, a 1% in aircraft size (measured in MTOW) gives rise to a 1.8% increase and a 1% increase in aircraft age generates a 0.69% increase in environmental effects. Similar results but with smaller magnitudes are observed if airport internalization is considered. Our policy implications are that the tariff internalizing the total amount of externality is about Euro 180 per flight, while the tariff limiting only

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pollution is about euro 60 and the one reducing noise is about euro 110. Moreover, our airport examples show that managers should prefer to address additional capacity by increasing frequency rather than aircraft size, since the former strategy is more environmental friendly.

KEYWORDS: Airport noise and pollution, factors affecting externalities, environmental charges, 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, registering an increase of 5.6% over 2010. Forecasts on future annual growth rates vary between 5.3% (IATA, 2014) and 7.5% (Airbus, 2012 Global Market Forecasts 2011-2031); hence, the increase 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 estimates (IPCC, 1999) show that the sector was responsible for about 2% of total carbon dioxide emissions in 1992 (about 13% of CO_2 emissions from all transportation sources), with a predicted increase to 3% by 2050. Environmental concerns are also linked to aircraft local emissions during airport operations (e.g., landing and take-off cycle - LTO, taxiing, 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., airport operators, companies, users, etc.).[1] Efforts to integrate externalities measures in air transport policies have been implemented both at the global (ICAO) and at the European level: evidence of them is provided in Section 2. While some estimates on the economic and ecological effects of these efforts are available (e.g., Vespermann and Wald, 2011)[2], very few studies have tackled the issue of estimating which factors may affect the amount of local emissions and the level of noise nuisance produced by this sector at the airport level. Hence, the goal of this paper is twofold: (1) to investigate the sign and the magnitude of some possible determinants of airports' local pollution

[1] ICAO has improved the standards imposed to aircrafts since 1970, through the adoption of different Chapters. 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 (implemented in Italy with the Legislative Decree n. 60/2002), which covers SO_2, NO_2 and NO_x, PM_{10} and Pb. 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.

2 They analyze the possible impacts of the EU ETS and show that its effects are likely to be moderate.

and noise (e.g., the annual movements, the fleet characteristics such as aircraft age and size, the different aircraft and engine manufacturers, etc.) and (2) to propose, as a policy implications, some tariff schemes adding some new elements to the environmental and noise charges already adopted in many European airports. These new elements (e.g., the impact of age, the identification of a single tariff for both externalities instead of two separated charges) may provide new insights on the trade-off faced by airport managers (e.g., the environmental effects of adding more passenger traffic in a specific airport will be lower by increasing flight frequency or the aircraft average payload?) and may help to design incentives to reduce the level of noise annoyance and the amount of local air pollution.

In order to analyze the factors affecting the airport environmental effects, we need a measure aggregating both the amounts of different pollutants and the noise annoyance levels generated by an airport in a period of time. The local air pollution generated by airport activities consists of different chemicals (e.g., nitrogen oxides, particular matter, etc.) while we need an aggregated weighted measure identifying the total amount of pollution generated by an airport; the latter is essential to obtain estimates regarding the possible determinants of local pollution. Moreover, differently from air pollutants, noise levels are computed in decibels, i.e. a logarithmic scale. Hence, we need (1) to linearize the noise and (2) to aggregate it to total pollution, so that we obtain a single measure of the total externalities created by an airport. We use as weights some monetary values that translate different amounts of chemicals and decibels into euros. These monetary values are given by some estimates, available in the literature (Dings et al., 2003, Schipper, 2004, Givoni and Rietveld, 2010, and recent updates from Eurocontrol, 2015) of unit externality costs for the different chemicals and for the noise level generated by a flight during airport operations. This means that we do not provide an estimate of the social costs produced by an airport (this would imply to consider explicitly in the analysis the population paying for such costs and may be investigated through specific case studies); rather, we analyze the annual amount of environmental outputs produced by all airports of a national system over time. The environmental levels are computed starting from the pollution and noise certification levels of each possible aircraft-engine combination operating in in the national system (Italy) during the observed period (10 years, 1999-2008). These aircraft-engine certification levels are uniform across all the airports, and do not depend upon airlines' effective operations (i.e., the load factors, the effective maximum-take-off-weight (MTOW), etc., which may differ across airlines and may produce LTO-cycle specific amount of pollution and noise) and airport capacity (i.e., the presence of adequate taxiways, the time elapsed from fingers to the runway, etc., which may influence the amount of fuel burnt by aircrafts during land operations and the noise contours).[3] Certification levels are then multiplied for the annual movements of each aircraft-engine combination observed in a specific airport. Hence, we obtain certification-based annual emission and noise levels that are different among airports because of the different aircraft fleets operating (i.e., their average age, size, manufacturers, etc.) and of the different volumes of activities. In this way we can investigate the heterogeneity among airports to identify which factors affect more the externalities, in which direction and magnitude, and which uniform tariff levels may reduce them, yielding a potential similar effect over the all country.

We compute the total amount of annual environmental outputs at the airport level, by aggregating in a single index two figures: one measuring the yearly amount of local air pollution and one quantifying the level of noise produced by aircraft operations during the landing-and-takeoff (LTO) cycle.[4] The two indices are based on aircraft/engine combinations and their certification values, established according to the ICAO Annex 16 (Vol. 1 and 2) and combine several information gathered by different databases: IRCA (International Register of Civil Aircraft) for data on engines installed on different aircraft, 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 at Italian airports over the period 1999-2008.

Moreover, since a portion of these environmental effects is internalized (e.g., in some airports regulation may affect flight paths so that they limit the impact on highly populated areas, or flight curfews at night), we also investigate a second scenario where we take into account that airports may differentiate in terms of environmental internalization. Hence, we first analyze the different policies for internalization adopted by each airport of the aviation national system and then we apply different weights for the amount of environmental effects produced yearly by each airport that depends upon the degree of internalization observed for each specific airport. In this second scenario we provide some empirical evidence on the possible determinants of airport potential environmental externalities, since they are not already internalized by the different companies operating in each airport and may generate negative impacts on the surrounding population.

The analysis is carried for a sample of 31 Italian airports representing about 90% of total annual aircraft movements to investigate the factors affecting their levels of environmental outputs.

[3] LTO-cycle specific environmental outputs are impossible to measure using the available datasets regarding all the airports of a national system. This would require a set of really detailed and specific information for each single take-off and landing operation in each airport, and these data may be computed, in a reasonable amount of time, only for a very limited amount of airports and not for a national system.

[4] Aspects related to vehicular traffic in proximity of airports and supporting activities for aviation (mostly passenger shuttle, catering service, etc., generally known as ground support equipment) are not considered here for lack of data. As mentioned before, airport infrastructures are not considered because they do not affect certification-based levels.

We study empirically the determinants of environmental effects by developing an econometric model having as explanatory variables factors as the yearly number of aircraft movements, the fleet age, the share of flights operated by low costs carriers (LCC), the share of flights of a specific aircraft manufacturer, etc. The empirical evidence is provided by applying an empirical model to a panel dataset that includes airport fixed effects capturing latent heterogeneity. We also investigate separately the determinants of pollution and of noise.

The paper is organized as follows: in Section 2 we review the literature on airport environmental effects, in Section 3 we briefly discuss the current regulation and the actions undertaken to internalize environmental effects at airports in Italy, while in Section 4 we present two indices describing the yearly amount of pollution and the level of noise produced by an airport. The empirical models are presented in Section 5, while the data set is discussed in Section 6. In Section 7 we explain the econometric results. Section 8 presents the policy implications and Section 9 highlights the main conclusions of the paper. In the Appendix we report some data on Italian airports.

2. Literature review and environmental regulation

Our contribution is linked with the few papers studying 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 focusing on a small sample of routes linking some of the main European airports. Hence, he does not consider a national system. Moreover, Schipper does not investigate with an econometric model the factors affecting the amount of environmental effects produced.

Lu and Morrell (2006) estimate the local environmental costs of noise and pollution in a limited sample of European airports (Heathrow, Gatwick, Stansted, Schipol and Maastricht), but do not investigate their determinants. Morrell and Lu (2007) apply the approach developed in their previous contribution to compare the environmental costs of two different models of organizing the aviation activities: hub-hub *versus* hub by-pass networks, and study a small sample of eight world airports. Lu (2009) considers the impact on airlines' demand of introducing emission charges, by adopting a methodology similar to Lu and Morrell (2006). Givoni and Rietveld (2010) study the environmental costs of linking some cities (e.g., London and Amsterdam, Tokyo and Sapporo) using two types of aircraft of different sizes (B747 and A320). Lu (2011) presents a study on the local environmental costs of airport operation at Taiwan Taoyuan international airport using the same approach adopted in Lu and Morrell (2006). Differently from all these contributions we try to investigate whether it is possible to identify the determinants of the amount of airport's environmental effects and the magnitude of their impacts, so that it may possible to provide incentives to limit them and to speed up the process of fleet renovation, and to give insight to airport managers when it is necessary to expand airport operations with limited negative outcomes on the surrounding environment.

Concerning the computation of the amount of environmental effects, there are also some differences between our approach and those of the literature. All the above contributions do not discriminate between aircraft and engine manufacturers and focus only on few representative aircraft models. These limitations make difficult to understand the environmental implications of different technological settings: for instance, it is not possible to quantify the difference in the pollution and noise produced if the same aircraft model is operated under different engine configurations; or which is the impact of technical progress on the environmental effects. Our paper is an attempt to provide some evidence on these issues by estimating an econometric model that may shed light on the effects of factors characterizing the aviation activities. However, we share with previous contributions the use of certification-based information, since LTO-specific effective pollution and noise levels (i.e., based on airlines standard operations and airport's infrastructures) for each aircraft-engine combination are not available.

3. Environmental regulation and internalization

In this section we briefly discuss the regulation adopted to limit pollution and noise, with a focus on local environmental effects since our aim is to analyse their possible determinants. We also analyse how limitations to airport operations are implemented in the Italian airports in the sample, so that it is possible to have a measure of the amount of environmental effects that are already internalized by aviation companies (airlines and airports).

Regulation of environmental effects of civil aviation focuses on airport charges and limitation of airport operations. Airport charges are usually based on certification data. For instance, ICAO aircraft certification classification according to chapter 2, chapter 3, and chapter 4 standards is the base for many noise charges adopted in European countries.[5] The noise charge is then increased in case of a night flight. The charges are very heterogeneous in Europe, for instance in Italian airports there are no noise surcharges at the moment.[6] Regarding emission charges, there is a small number

5 Typically, a noise charge is a per-flight amount that is very high if the aircraft has no ICAO certification or fulfils chapter 2 standards, and is very low (or equal to 0) if it satisfies chapter 4 standards. For instance, Frankfurt airport has 12 noise classes based on ICAO aircraft noise certification values and the noise charge varies between €25.50 and € 19,000 per landing and per take-off (the last charge applies to AN 124 and IL 76 aircraft with certified noise level equal or over 96dB(A)).

6 A very useful summary of noise and emission charges in Europe and in many other States is at the website: http://www.boeing.com/boeing/commercial/noise/list.page? At the end of 2011 the European Commission (EC, 2011) has approved a general framework for noise charges, establishing that each aircraft has to provide to the airport its

of European airports that have adopted them (based on certification values), while no Italian airport has implemented them yet.[7] .

The European current emission and noise surcharge framework could be improved in terms of both homogeneity across countries and elements involved. A unique methodological approach for the European airports would give to airlines a uniform regulatory environment yielding in every member state the same incentives for a sustainable development. Moreover, new elements could be introduced: the aircraft age does not enter into the regulation settings yet, even if age may be an important determinants of airport externalities. In addition, the aircraft size can directly enter the settings, since it may provide a further incentive to airline to optimally choose the best size for each route. Last, rather than splitting charges between noise and emissions, that may create a tension between these two dimensions if they are not strongly correlated, a unique charge for the aggregated level of externalities produced by each flight during the LTO cycle may provide better incentives in terms of global (and not single-dimension) sustainability. Our policy implications may be a first attempt to address these issues.

The second dimension of environmental regulation in aviation is based upon airport operation restrictions. They include flight curfews at nights, constrained flight paths for take-over and landing, no-fly times, etc. Table 1 shows the list of Italian airports included in the analysed sample, their locations and the presence of noise limitations. The latter is divided into (1) night curfew period and (2) constrained flight paths during the LTO cycle. Only 9 Italian airports out of 31 included in the sample have flight limitations during the night, between 23:00 and 6:00. Milan Malpensa and Rome Fiumicino have no night curfews but “partial” limitations such as the obligation of runway operations different from those adopted during the day (in order to reduce the noise nuisance) or the prohibition to operate flights with noise aircraft (e.g., ICAO Annex 16 Stage 1 aircraft). All airports have constrained flight paths. Hence, even if we acknowledge that there might be a trade-off between noise internalization and emissions (longer flight paths may generated higher emission levels), in the Italian case this effect seems to be uniformly distributed across airports, so that this potential trade-off may not be considered in the determinants’ analysis (it may only add the amount of pollution generated at all airports). At each airport is also assigned a

certified noise levels and its MTOW (an heavier aircraft is usually noisier), and any eventual engine modifications; moreover the Commission has delegated each member state to adopt a regulatory framework concerning noise and emission surcharges that should be applied to three classes of airports: those with more than 5 million yearly passengers, those between 3 and 5 millions and those with less than 1 million.

7 The few emission surcharges adopted in European airports are based on ICAO aircraft classification. Aircraft emissions are reported in ICAO Annex 16 and are reviewed periodically by CAEP (from January 2008 CAEP 6 standards are implemented). Emission surcharges are mainly based on NO_x emissions starting from ICAO certification values for each aircraft and based on the ERLIG (Emission Related Landing Charges Investigation Group) formula by ECAC. For instance Frankfurt airport charges €3 per kg of NO_x emitted during the LTO cycle with emission factors (i.e., the conversion from fuel consumption to NO_x emission) based on the ICAO certification values.

location category according to the population density of the area: rural means that the airport is located rather far from the city in a low population density area, medium that its surroundings have a moderate population density while urban implies that the airport is within the city or at its borders, in a high population density area. As shown noise limitations are present (during the observed period i.e., 1999-2008) in all “urban” airports and in some “medium” airports (e.g., Milan Malpensa and Rome Fiumicino), that are located very far from the cities, but have a large number of annual aircraft movements.

Table 1. Airport location and noise restriction in Italy, 1999-2008

Airport	Airport location	Night curfew period	Constrained LTO path	Airport	Airport location	Night curfew period	Constrained LTO path
Alghero	Medium		YES	Milan Malpensa	Medium	PARTIAL (only 1 runway)	YES
Ancona	Rural		YES	Naples	Urban	23.00 - 6.00	YES
Bari	Medium		YES	Olbia	Rural		YES
Bergamo	Urban	23.00 - 6.00	YES	Palermo	Rural		YES
Bologna	Urban	23.00 - 6.00	YES	Pescara	Rural		YES
Brescia	Rural		YES	Pisa	Medium		YES
Brindisi	Rural		YES	Reggio Calabria	Rural		YES
Cagliari	Medium		YES	Rimini	Rural		YES
Catania	Medium	23.00 - 6.00	YES	Rome Ciampino	Urban	23.00 - 6.00	YES
Crotone	Rural		YES	Rome Fiumicino	Medium	PARTIAL (only 1 runway)	YES
Florence	Medium		YES	Turin	Medium		YES
Forlì	Medium		YES	Treviso	Rural		YES
Genoa	Rural		YES	Trieste	Rural		YES
Lamezia Terme	Rural		YES	Venice	Medium	23.00 - 6.00	YES
Lampedusa	Rural		YES	Verona	Rural		YES
Milan Linate	Urban	23.00 - 6.00	YES				

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The presence of noise restrictions represents an attempt to internalize the environmental effects connected with noise nuisance at the airport level. By changing flight curfews at nights and by forcing aircraft to take-over and to land using different flight paths in presence of residential areas the civil aviation regulators aviation try to transfer part of the noise costs to airlines and airports. These decisions have two effects in the sample we are going to investigate: (1) night flight curfews reduce the aircraft movements; (2) constrained flight paths, which are mainly adopted in areas where the airport is surrounded by medium/high population density, induce sub-optimal operations, e.g., longer flight paths. The first effect, lower movements, is embedded in our data, since we compute a measure of airport environmental effects which is also based on annual aircraft movements. This implies that the component of internalization activities related to flight limitations is already included in our environmental effect measure. The second effect implies higher costs: in order to avoid bad noise effects on the population living nearby a urban airport the take-over and landing path is sub-optimal and involves more fuel consumption and, in turn, more pollution. This implies that airports in urban areas should have higher weights when computing the aggregate measure of environmental effects; regulation implies that some operations are internalized and being sub-optimal they become more expensive. We accommodate this effect by assigning an higher weight to the noise level produced in a urban area airport and a lower weight to an airport located in a rural area. Hence, when we compare this second scenario with the previous one, based on (uniform) certification values, we can appreciate what is the impact on the determinants of airport environmental effects of regulation (leading to higher weights because of sub-optimal operations), in contrast with the no internalization scenario based on uniform weights (our baseline model).[8]

4. An airport measure of environmental effects

Here we present the methodology to obtain an airport measure of the emissions and noise produced during a year. Our aim is to provide an approach that is applied to the aircraft fleets operating in the different airports, taking into account their different characteristics. The aggregated environmental effects cannot be considered as a social cost since the latter would require to take into account the population living around the different airports. However, our measure represents a good proxy of the amount of environmental effects generated by airport's operations and so it may be used to investigate which factors, and with which magnitude, increase or decrease it. Moreover,

[8] We are grateful to an anonymous referee for raising this issue. Clearly, airlines may pass these internalized externality costs to passengers. However, this means that there is a distributive effects between airlines and passengers, but the social costs are always internalized.

we consider also a scenario where we take into account whether regulations has forced airlines and airports to implement action to internalize part of the produced environmental effects, especially noise

First, we describe two indices measuring the amount of pollution and noise produced by a specific aircraft model, based on certification values. Second, we apply such indices to the movements observed in a specific airport during a year to obtain two (i.e., one for the local air pollution and one for the noise) yearly environmental effect measures. In doing so we implement a methodology based on several databases, each one adding relevant information about the amount of pollution and the level of noise produced by an aircraft during the LTO cycle. Then, we convert the obtained measures, which are expressed in quantities of pollutants and in decibels, into monetary values and sum them in order to get a single aggregate measure of the environmental effects produced by the airport's operations during a year. Last, when we take into account the possible internalization of these effects we adjust these weights in order to consider the portion that is already included in private costs.

4.1 The amount of local air pollution generated 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 above ground, lasting 2.2 min), approach (from 3000 ft to landing, lasting 4 min), and idle (when the aircraft is taxiing or standing on the ground with engines-on). The 3000 ft (approximately 915 m) boundary is the standard set by 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), and nitrogen oxides (NO_X).[9] In addition, the Annex 16 original reference values for certificated pollutants were

[9] ICAO also provides the limits for carbon monoxide (CO), which, however, has negligible estimated costs on human health (Dings et al., 2003, Givoni and Rietvield, 2010), and so it has not been included in the analysis. The limits for 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 production date of the engine under investigation, to take into account for possible engine upgrades.

reviewed by the CAEP and periodically modified by introducing more stringent criteria.[10] 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 burnt (mass of pollutant in gr/mass of fuel in kg).[11]

In addition to the production of HC and NO_X, following earlier studies (Dings et al. 2003, Schipper 2004, Lu and Morrell 2006, Givoni and Rietvield 2010), we also consider the production of sulphur dioxide (SO_2) and suspended particulate matter (PM_{10}).[12]

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.

The starting point of the procedure is given by the aviation operations in a specific airport, which are obtained from OAG. The latter provides information about each flight operated in an airport during a year including the aircraft model used by the operating airline. Hence, the information refers to a single flight (not only to a route). However, OAG does not provide information about the engines installed on the aircraft, 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 on a specific aircraft, the second step in our procedure consists in matching the OAG information with the ICAO Engine Emissions Databank, which provides the certification information for each engine type. It specifies, for each phase of the LTO cycle, the HC, and NO_X emission factors and the fuel consumption.[13] For each LTO phase, emission factors have been multiplied by their duration (the so-called time-in mode) and fuel consumption, to obtain the amount of HC and NO_X produced. These per-phase amounts are then aggregated to obtain the amount of HC and NO_X produced by each engine type during each departure or arrival operation.

Regarding the amount of SO_2 and PM_{10} produced at the airport level, the computation is performed as follows: 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, Givoni and Rietveld 2010), that is

[10] 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 and CAEP 8. New limits have been set assuming a percentage reduction on the previous values.

[11] The emission factors are recorded by ICAO in the Engine Emissions Databank, managed by the UK Civil Aviation Administration and available on the Internet.

[12] CO_2 has not been included in the analysis since it has no effects on local pollution, while it has an impact on global warming. Since the latter is outside our analysis we do not consider carbon dioxide in this contribution.

[13] The ICAO LTO cycle model is divided into four phases: (1) take-off, 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.

equal to 0.8 grams per kilogram of fuel burnt for SO_2 and to 0.2 g/fuel for PM_{10}.

The last step of the procedure is the matching between the aircraft model operating a flight 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 2 shows the frequency of each engine type installed on the Airbus A320. The highest percentage of currently operating A320s has the V2527-A5 engines, produced by the International Aero Engine (IAE) manufacturer, while the second percentage is given by A320s with the CFM 56-5A3 engines, 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.[14]

The only exceptions in the above procedure are the amounts of pollutants emitted by aircraft belonging to the *easyJet* and *Ryanair* fleets, since these two airlines have a business model with a single aircraft in operation (respectively, A319 and B737); moreover, *Ryanair* has a strong market share in the Italian market, while easyJet is particularly important in some airports (e.g., Milan Malpensa). In this case we use the emission factors of the models used by these two airlines, i.e., B737 with engine CFM 56-7B-27 for *Ryanair*, and A319 with engine CFM56-5B4/3 for *easyJet*.[15] However, we do not make any specific assumption regarding the engines installed on the Alitalia fleet, which was the main carrier for most of the analysed period, because its fleet is heterogeneous, involving turbo propellers, narrow-bodies and large-bodies as for many traditional carriers; the IRCA engine distribution may reasonably provide a good proxy for the engines installed on the fleet of aircraft operated by Alitalia.

Table 2: 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

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

[15] We are grateful to an anonymous referee for raising this issue.

The final outcome of the above procedure is an engine-weighted average value for each of the four pollutants emitted during the LTO cycle by each aircraft model. In order to compute the total quantity of pollutant p produced by aircraft i during the LTO cycle, and defined as Q_p^i, we need to consider (i) the number of engine installed on each aircraft, (ii) the engine specific emission factor, (iii) the fuel consumption during the LTO cycle and (iv) the time length of each LTO phase (take-off, climb-out, approach and idle); this leads to the following equation:

$$Q_p^i = n_j^i \times \left(\sum_{f=1}^{4} E_{pjf} \times d_f \times Fc_{jf} \right) \qquad (1)$$

where n_j^i 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 3 presents the pollutants emitted by Airbus A320, A321 and Boeing B737 (in 7 different model specifications) during the departure phase of the LTO cycle. It is evident that there is a quite relevant heterogeneity among these commonly used aircraft models.

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

Aircraft	HC	NO_X	PM_{10}	SO_2
Airbus A320	0.304	9.031	0.120	0.481
Airbus A321	0.691	13.569	0.141	0.563
Boeing 737-200	2.083	6.519	0.135	0.539
Boeing 737-300	0.538	6.337	0.115	0.461
Boeing 737-400	0.439	7.376	0.124	0.495
Boeing 737-500	0.450	7.326	0.123	0.493
Boeing 737-600	0.682	6.670	0.105	0.421
Boeing 737-700	0.626	8.350	0.116	0.464
Boeing 737-800	0.554	9.636	0.123	0.490

Source: computation on ICAO and IRCA databases

Table 4 presents the same values but for the arrival phase. In addition to the above mentioned model heterogeneity it is evident that emissions are lower during arrivals than departures.

Table 4: Engine-weighted average pollutants (kg), A320, A321, B737, arrivals.

Aircraft	HC	NO_X	PM_{10}	SO_2
Airbus A320	0.167	1.861	0.051	0.202
Airbus A321	0.404	2.367	0.057	0.229
Boeing 737-200	0.898	1.396	0.056	0.224
Boeing 737-300	0.205	1.656	0.049	0.196
Boeing 737-400	0.168	1.852	0.052	0.208
Boeing 737-500	0.172	1.844	0.052	0.208
Boeing 737-600	0.254	1.719	0.045	0.179
Boeing 737-700	0.234	1.936	0.049	0.194
Boeing 737-800	0.207	2.128	0.051	0.203

Source: computation on ICAO and IRCA databases

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:

$$P_{ph} = m_h^i \times Q_p^i \qquad (2)$$

The aggregated amount of emissions generated by an airport during a year is defined as Local Air Pollution (LAP) index (LAP_h), and it is computed by multiplying each quantity of pollutant for its estimated weight in terms of unit (euro for kilogram of chemical) health costs, as provided by Dings et al. (2003). The latter is a comprehensive contribution providing the state-of-the-art on external cost of aviation, and it represents a synthesis of all the investigations performed over the time on local pollution. Dings et al. (2003) refers to European airports and so its estimates of unit externalities costs can be applied to Italy. In evaluating the unit costs they have focused on the health effects of local air pollutants, and found that PM_{10} has the highest unit (per kilogram of pollutant emitted) impact on human health by far, and HC the lowest. This implies that the four pollutants have different weights in the total amount of local pollution generated by airport activities. These weights, taking into account the evidence available, are given, according to Dings et al. (2003) by a unit cost equal to euro 4 per kilogram of HC produced during the LTO by an aircraft; to euro 9 per kilogram of NO_x, to euro 150 per kilogram of PM_{10} and to euro 6 per kilogram of SO_2.[16] These estimates are in euro-1999 base; moreover, to check for the robustness of our econometric results, we will perform a sensitivity analysis by providing different weights to the four pollutants, while keeping however their ranking fixed.[17]

The LAP index, i.e., the aggregated weighted amount of yearly emissions in airport h, is then obtained as the sum of the kilograms produced of each pollutant p weighted for its relative unit cost, i.e., C_p, where C_p is the weight (i.e., in our baseline scenario, euro 4 for each kg of HC, euro 9 for

[16] As shown in Tables 3-4, the kilograms of PM_{10} produced during the LTO is much smaller than the kilograms of NO_x; hence, even if PM_{10} has the highest unit cost, NO_x has the greatest total impact on the amount of local pollution generated.

[17] It may be argued that weights taken from Dings et al. (2003) should be updated. However, even the recent Eurocontrol report on cost-benefit analysis in the aviation sector (Eurocontrol 2015), has simply adjusted monetary weights taken from the same source or from a similar period publication. Hence more recent measures are not available yet. Eurocontrol gives a unit damage cost in euro-2015 base equal to euro 11.5 per kg of NO_x, to euro 11 per kg of SO_2 and to euro 30 per kg of $PM_{2.5}$ in rural area airports, euro 76 per kg of $PM_{2.5}$ in medium areas and euro 292 in urban airports, $PM_{2.5}$ differs from PM_{10} for the size of the very small particular matter (the former has a smaller dimension). $PM_{2.5}$ can reach the lung while PM_{10} can reach the larynx. Hence $PM_{2.5}$ is more dangerous and so it involves higher costs. .

NO_x, euro 150 for PM_{10} and euro 6 for SO_2):

$$LAP_h = \sum_{p=1}^{4} C_p \times P_{ph} \quad (3)$$

4.2 The level of noise generated in airport operations

The level of noise generated yearly by airports is computed using a procedure similar to the one adopted for emissions. The level of noise of 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 (e.g., the manufacturer, model, maximum take-off weight, engine type and number, and noise certification data) on the vast majority of aircraft models. OAG records reporting the airports movements operated by a specific aircraft model have been then 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 take-off weights.[18] The same procedure presented before for emissions gives rise to the computed noise levels shown in the Airbus A320, A321 and Boeing B737 examples reported in Table 5.

Table 5: Average noise levels (dB), A320, A321, B737.

Aircraft	Approach _Level	Lateral _Level	Flyover_Level
Airbus A320	92.5	95.1	85,4
Airbus A321	96.4	96.4	88.8
Boeing 737-200	96.7	96.4	90.7
Boeing 737-300	90.3	99.0	85.0
Boeing 737-400	91.8	99.3	86.8
Boeing 737-500	89.7	97.9	81.7
Boeing 737-600	91.2	95.7	84.8
Boeing 737-700	92.8	96.0	85.0
Boeing 737-800	93.6	95.9	84.1

Source: computation on EASA/FAA and IRCA databases

As shown in Table 5 the amount of noise produced by an aircraft during a LTO cycle is certified in three different points, located nearby the airport: a Lateral measurement point, an Approach point and a Flyover point. The certification data are in Effective Perceived Noise Level (EPNL) 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

[18] 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 an 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.

irregularities and duration of the event. To evaluate landing operations a 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).[19] Table 4 shows that the highest noise levels are measured at Approach and Lateral points, while lower levels are registered at 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 (e.g., A320 in approach has a EPNL equal to 92.5, while B737-200 has 96.7, implying more than the double of noise level).

The next step in the noise computation is to get an average noise level for aircraft i, labeled as AN^i given by the following expression:

$$AN^i = 10 \times log \times \left(\frac{1}{3} \times \sum_{q=1}^{3} 10^{EPNL^i/_{10}} \right) \quad (4)$$

where AN^i is the energetic mean of the EPNL values at the reference points $EPNL^i_q$.[20] AN^i is augmented by a penalty W in case of night flight, with W = 10dB.[21] However, for the purpose of our analysis we need to compute a level of noise that can be later aggregated to the amount of pollution, to get a single value for the total externalities produced by an airport. Hence, we consider as a reference the average noise social cost of an aircraft flight estimated by Schipper (2004), and equal to Euro 324.[22] Hence, taking as reference euro 324 and given that a decrease/increase of 3dB corresponds to a half/double level of noise exposure, and that the average noise level in our database corresponds to 95.3 dB, each AN^i is converted into Euro through the following expression:

[19] 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.

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

[21] A crucial feature of noise level is the distinction between night and day flights, since night flights generate more noise annoyance than daily ones. We are grateful to an anonymous referee for raising this issue.

[22] Schipper (2004) gives an estimate of Euro 281 of the noise costs per aircraft flight. The estimate is for year 1995 and has been inflated using the OECD deflator to year 1999, the same period of time of Dings et al. (2003) unit emission weights.

$$MAN^i = 2^{\frac{95.3 - AN^i}{3}} \times 324 \qquad (5)$$

where MAN^i is the monetary value of the noise exposure of a flight operated by aircraft i in a given airport.[23] Again, to check for the robustness of our results, we have performed a sensitivity analysis using different weights for the unit noise costs: we have considered a lower bound estimate provided by Schipper and equal to euro 198 (the original value of euro 171 has been expressed in 1999 euros, as all the other weights), and some other estimates provided by Dings et al. (2003), that are based on aircraft groups having different available seats, and equal to, respectively, euro 90, euro 150, euro 300, and euro 600.[24]

Last, since we need a yearly estimate of the amount of noise produced by airport h, we have summed the MAN^i values over the number of movements[25] operated in airport h by aircraft i (i = 1,…, I), where I represents the number of aircraft types operating in airport h during an year. The movements of each aircraft are split into daily and night flights, with M_D being the total number of daily flights of aircraft i, and M_N the total number of night flights (night flights have the penalty W explained before). All flights are summed over all the aircraft types operated at airport h. Hence, if we define MAN^h as the yearly amount of noise of airport h, this is given by:

$$MAN_h = \sum_{i=1}^{I} \sum_{m=1}^{M_D} MAN_m^i + \sum_{i=1}^{I} \sum_{m=1}^{M_N} \left(MAN_m^i \right) \qquad (6)$$

4.3 The airport measure of environmental effects

Since our aim is to compute an airport measure of environmental effects produced during a year, we need to sum the aggregated level of pollution and the yearly level of noise. Hence, we define another index (labeled *TE*, total environmental effects) as follows:

$$TE_h = LAP_h + MAN_h \qquad (7)$$

where *TE* is the main dependent variable in our empirical models, since our aim is to identify the sign, the statistical significance and the magnitude of some factors that may affect the amount of environmental effects generated. Moreover, we are also interested in verifying whether these factors

[23] The formula in equation (5) has to be interpreted as an attempt to linearize noise, since it is expressed in a logarithmic scale (decibels).

[24] Eurocontrol (2015) provides some measures for the aviation noise cost. However, they are either in noise costs per person-per year (computed for different noise exposure levels), using CE Delft (2011) as reference, or they are taken from Morrell & Lu (2007) which, in turn, work on 2000 data. Hence Eurocontrol (2015) has measures for noise costs adjusted from the same period of the measures by Dings et al. (2003) and Schipper (2001) adopted in this contribution.

[25] To avoid double counting the movements considered are related only to take-offs.

have different impacts on the production of pollutants and on the noise generation; hence, we also develop two further regression models where *LAP* and *MAN* are treated as dependent variable.

It is important to underline that the specific goal of our investigation does not consist in providing an estimate of the social costs of noise and pollution in a specific airport (or in a limited number of structures). In this case we would need to carefully consider the density of the population living nearby each airport. In contrast, we want to identify how some factors (e.g., aircraft age, size, engine manufacturer, etc.) influence the level of environmental effects produced, having as field of observations a national airport system and not a specific infrastructure. This means that if we assume that our results show a negative effect of aircraft size on the generation of noise we can state that, on average, larger aircraft are noisier than smaller ones, this result would be of value independently from the density of the population living nearby the airport.[26] As a result, a national regulatory model could include aircraft size in airport environmental charge mechanism. However, given that the estimated econometric coefficient gives the average effect taking into account all the other data and keeping them constant, this would not necessarily imply that a specific aircraft model (e.g., a new A380) is noisier than a smaller one (e.g., the B777) because all the other determinants have to be taken into account. Indeed if we assume that the empirical evidence is such that also age affects negatively the noise generation (meaning that, on average, new aircrafts give rise to less noise than older ones) the younger age of A380 in comparison with B777 may counterbalance the negative size effect (for A380), and may give, as a final effect, that A380 is less noisy than B777 (it is a matter of the magnitude of the estimated coefficients and of their application to A380 and B777 size and age characteristics).

In computing an airport measure of environmental effects we also consider a scenario where noise regulations dictate actions to internalize part of the effect. We tackle this issue by increasing the weight assigned to noise in presence of such internalization. We adjust the weight by observing whether the airport is located in a rural, medium and urban area. As mentioned before, the possible presence of night curfews do not change the weight since it is already included in the annual aircraft movements. To adjust the weight for airport localization we exploit the different weights available in the literature and used for the sensitivity analysis: Dings et al. (2003) low-medium monetary costs (euro 150) is the noise weight for airports in a rural area, Schipper (2004) high monetary cost (euro 324) is the weight for airports in a medium population density area, and Dings et al. (2003) highest monetary cost (euro 600) is the noise weight for airports in urban areas. Table A2 in Appendix provides the details for the different weights adopted at each specific airport.

[26] Notice that this would not necessarily imply that a specific large aircraft (e.g., a new A380) is noisier than a specific smaller aircraft (e.g., the B777), but that, on average, the effect of all the large aircrafts on noise generation is higher than that of smaller aircraft

5. An empirical analysis on the determinants of airports' environmental effects

In this Section we present an econometric model to investigate which factors may affect the aggregated amount of environmental effects produced by a national aviation system in its airports. Moreover, we also estimate their separated effects on pollution and noise. We consider as potential determinants variables related to (i) airport activities, (ii) airport characteristics, (iii) airlines characteristics, and (iv) fleet characteristics. Regarding airport activities we analyze the effects of the yearly number of air traffic movements (*ATM*), while for airport characteristics we consider the ownership. More in details, we take into account that previous contributions highlight that ownership is a determinant of airport performances (e.g., Oum et al., 2008, Scotti et al., 2012) also when environmental externalities are considered (Martini et al. 2013).[27] Moreover, as mentioned in Section 2.1, airports have heterogeneous attitudes regarding environmental charges, and this allows to investigate whether there is a particular ownership effect in the aviation system. Hence, we analyze whether public airports are more environmentally friendly than private ones (which may be profit maximizers and, hence, not willing to internalize environmental effects), by including the dummy variable, *PRIV*, equal to 1 if the majority of airport's shares is controlled by private subjects.

Airlines characteristics are captured by the presence of low cost carriers (LCC), i.e. *Ryanair* and *easyJet*, the two most important LCCs in Italian market.[28] The aim is to investigate whether LCCs have an effect on environmental effects generated at airports, given that they tend to operate a single type of aircraft (in Europe) and that they are relatively young actors declaring to be environmentally friendly. Hence, we include the share of airport movements operated by *Ryanair* (*RYAN*) and *easyJet* (*EASY*).

Fleet characteristics are given by variables reflecting some features of the set of aircraft-engine combinations operating during a year in a specific airport. We consider the aircraft average size (expressed in terms of *MTOW*), the aircraft average age (*AGE*)[29]. As control variables we include two variables discriminating among aircraft manufacturers: the share of airport movements

[27] Martini et al. (2013) show that public airports are more efficient than private airports in terms of technical/environmental efficiency.

[28] We do not consider as determinant the share of cargo flights because (1) almost 70% of freight is carried in passengers aircrafts and (2) the OAG dataset does not show the amount of freight transported in passengers aircrafts (but only if the flight is a 100% freight flights, giving rise to a very small percentage (1%) of total flights in Italy.

[29] Aircraft age is based on the date of certification for each aircraft/engine combination. Then, the variable *AGE* is the average age of the fleet obtained by weighting the age of each aircraft/engine combination by its share of annual movements.

operated by a *Boeing* aircraft (*BOEING*) and the share operated by a *Airbus* aircraft (*AIRBUS*).[30] Furthermore, we also include as controls some variables related to the engine manufacturer, i.e., the share of airport flights operated with a CFM International engine (*CFM*), a IAE engine (*IAE*), a Pratt&Whitney engine (*PW*), a General Electric engine (*GE*) and a Rolls-Royce engine (*RR*).[31]

We apply the econometric model to a panel data set composed by *H* airports during *T* periods (years), introducing airport fixed effects capturing airports' latent heterogeneity, i.e., factors that are time-invariant and not included in the available data (e.g., the management ability, the long-term relationships with some airlines, the environmental regulation, the capacity restrictions, 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 varies across periods and airports) and against the null hypothesis 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 a logarithmic transformation for total environmental effects, annual aircraft movements, aircraft size and age. Hence, the estimated coefficients regarding these variables are elasticities, and may provide relevant information for designing incentives for airports and airlines to reduce the amount of pollution and noise produced at the local level. The econometric model is given by the following expression:

$$\begin{aligned}\log TE_{ht} = \alpha_0 + \alpha_h + \beta_1 \log ATM_{ht} + \beta_2 \log MTOW\_ATM_{ht} + \beta_3 RYAN_{ht} + \beta_4 EASY_{ht} + \\ + \beta_5 \log AGE_{ht} + \beta_6 AIRBUS_{ht} + \beta_7 BOEING_{ht} + \beta_8 CFM_{ht} + \\ + \beta_9 IAE_{ht} + \beta_{10} PW_{ht} + \beta_{11} GE_{ht} + \beta_{12} RR_{ht} + \delta_1 PRIV_{ht} + \mu TIME + \varphi_{ht}.\end{aligned} \tag{8}$$

where TE_{ht} is the total aggregated environmental effects 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, $MTOW\_ATM_{ht}$ is the average aircraft size per movement, and ε_{ht} is the error term, which is assumed to be white noise (all the other variables have been explained before).

Equation (8) represents our base model – namely Model #1. We have also regressed on the same set of explanatory variables $log(LAP_{ht})$, Model #2, and $\log(MAN_{ht})$, Model #3, treating

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[30] Hence, the baseline aircraft manufacturer is represented by all the other manufacturers (i.e., Embraer, ATR, Fokker, etc.). We acknowledge that the *Ryanair* and *easyJet* dummies, and the *Airbus* and *Boeing* binary variables are not fully independent, since the Irish LCC only operates *Boeing* 737s and *easyJet* only *Airbus*. Hence, when estimating the effect of an LCC dummy, we should also consider the marginal effect on the aircraft manufacturer. However, as shown in Table A5 in Appendix the correlation indices *Ryanair/Boeing* and *easyJet/Airbus* are positive but not very high (especially for Ryanair, only +0.11); moreover, our estimates for *Ryanair* and *easyJet* are likely to be slightly biased upward since these LCCs have installed younger generation engines in their fleets.

[31] The baseline engine manufacturer is then given by all the other companies (i.e., Allison Engine Company, KKBM, etc.).

separately local air pollution and noise in order to capture separated effects on pollution and on noise. The latter may provide useful environmental-specific information and may be considered in case policy makers intend to define separate tariffs aiming at providing incentives toward either greener fleets or less noisy ones.

Last, we also run some robustness checks: Models #4-#5 have different monetary values for the weights assigned to the four pollutants considered, given by the other two different specifications provided by Dings et al. (2003): a lower bound weight, where the unit value for kilogram of HC produced is equal to euro 3, for NO_x to euro 7, for PM_{10} to euro 70 and for SO_2 to euro 4 (this is Model #4); and a higher bound, with euro 10 for HC, euro 12 for NO_x, euro 300 for PM_{10} and euro 10 for SO_2 (Model #5). Regarding noise, we have considered different specifications for the unit value assigned to the representative aircraft and then modulated according to equation (4): we have controlled for the lower bound value indicated by Schipper (2004) equal to euro 171 (Model #6, updated to year 1999 to euro 198), and those proposed by Dings et al. (2003) (which are however more aircraft category specific), and equal to euro 90 (Model #7), to euro 150 (Model #8), euro 300 (Model #9) and euro 600 (Model #10).

6. 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 and their size (given by the 2008 annual number of aircraft and passengers movements) is shown in Table A1 in the Appendix at the end of the paper.

Table A3 in Appendix presents the descriptive statistics on all the variables included in the econometric models #1-#3, and their meaning. During the period 1999-2008 on average an Italian airport has produced yearly an aggregate measure of environmental effects (*TE*) equal to about 6.4 million Euro, of which about 2.2 million Euro regarding pollution (34.4%) and about 4.4 million Euro due to noise levels (65.6%). The lowest production is about only 10 thousand Euro, while the maximum is about 66 million Euro. The representative airport has about 37 thousand 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 15% of the total (with a maximum of 100% flights in some airports), while *easyJet* ones are only 1% but with a maximum of 18% in one airport (Milan Malpensa). Flights operated with Airbus aircraft are 12%, while those operated with Boeing aircraft are 54%. The share of flights with aircraft equipped with CFM International engines is 38% of the total, those with Pratt&Whitney engines are 44%, with General Electric engines 5%, with Rolls-Royce engines 4%, and with IAE engines only 2%.

Table A4 in Appendix shows the descriptive statistics regarding the different pollution and noise variables entering as dependent variable in Models #4-#10. We have analyzed the Kendall correlation index among all the variables. It is interesting to notice that negative correlation indices for the aggregate environmental effects (*TE*) are found with the share of *Ryanair* flights (*RYAN*), the share of flights operated with Boeing aircraft (*BOEING*) and with aircraft with Pratt&Whitney engines (*PW*). Interestingly, aircraft age (*AGE*) is negatively correlated with *RYAN* and *EASY*, confirming that LCCs operate aircraft models relatively younger than other airlines. Correlation is particularly high between total environmental effects (*TE*) and movements (*ATM*), and between *TE* and *MTOW*.

7. Econometric results

We present in this Section the econometric results regarding the determinants of environmental effects. The impacts of the explanatory variables in Models (1)-(3) are shown in Table 6, reporting the coefficients' estimates for all the variables under three different specifications of the dependent variable: Model #1 for aggregated environmental levels (*TE*), Model #2 for aggregated pollution (*LAP*) and Model #3 for noise levels (*MAN*).

The regression with *TE* as dependent variable has a positive and highly statistically significant coefficient for the aircraft movements *ATM*. Being both *TE* and *ATM* expressed in logarithms, the 1.05 estimated coefficient implies that a 1% increase in annual aircraft movements yields a 1.05% increase in total environmental levels, *ceteris paribus*. Similarly, we get an elasticity estimate for the impact of aircraft size looking at the estimated coefficient for *MTOW_ATM* that is equal to 1.81, and it is highly statistically significant. Hence, a 1% increase in the aircraft size per movement gives rise to a 1.81% increase in the total amount of environmental effects produced.

Ryanair has a positive effect on *TE*, since the estimated coefficient is positive and statistically significant, while *easyJet* has no effect: the coefficient is equal to -0.18 but it is statistically insignificant. However, these coefficients are not elasticities, since the explanatory variables are not in logarithms. The estimated coefficient for *Ryanair* points out that, after having taken into account for the total number of movement, the fleet age, the size per movement (and all the other factors shown in Table 6) (i.e., *ceteris paribus*), an increase in the share of flights operated by the Irish LCC leads to an increase in the level of total environmental effects produced in the Italian airports. This may be explained with the utilization by *Ryanair* of aircraft that are particularly noisy, as shown by coefficient estimated in Model #3, where the dependent variable is the noise level (the coefficient is equal to 0.29 and it is statistically significant). Concerning the ownership effect, the estimated coefficient of *PRIV* is negative and statistically significant. It implies that airports with private ownership have lower total environmental levels than airport with public ownership.[32] This higher attention for the environment in presence of private airports may be explained in terms of a very high sensitivity of private airport managers concerning green activities since they are particularly oriented to avoid public opinion accusations of profit maximizing behavior without considering the welfare of the population living nearby the airport.

[32] This insight is not influenced by airport size, since some private Italian airports have a large size (e.g., Rome Fiumicino, see Table A1 in Appendix). The latter condition is important since it is possible to argue that private airports are of smaller size and with a greater share of turboprop traffic, which may reduce the environmental effects.

The estimated coefficient of *AGE* is positive and statistically significant: since *TE* and *AGE* are expressed in logarithms, it implies that a +1% in the fleet age gives rise to a +0.69% in total externality levels, *ceteris paribus* (i.e., having already taken into account the impact of movements, aircraft size, etc.); this estimated age effect may incorporate the aircraft-specific embedded technical progress, given that younger aircrafts seem to be more environmentally friendly. Regarding control variables, *Airbus* and *Boeing* have both a negative and statistically significant impact on *TE*, meaning that their aircrafts are greener than those produced by other manufacturers (the effect of *Airbus* is higher). Again, this result is *ceteris paribus*, i.e., after having taken into account the impact of other factors such as age, size etc. Among the engine manufacturers, both *CFM* and *PW* have a positive effect on *TE*, meaning that aircrafts with engines produced by *CFM* and *PW* increase total environmental levels, mainly due to the noise impacts as shown by the estimated coefficients in Model #3. There is also, as expected, a positive estimated effect of technical progress, since the variable *TIME* has a weakly statistically significant negative coefficient (-0.007).

Table 6: Panel Data Model Econometric results Models #1-#3

	Econometric Model					
	Model #1† Dep. Variable: TE		Model #2† Dep. Variable: LAP		Model #3†† Dep. Variable: MAN	
Indep. Variables	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
ATM	1.054***	0.020	1.055***	0.018	1.001***	0.014
MTOW_ATM	1.806***	0.103	0.742***	0.094	2.024***	0.112
RYAN	0.21**	0.085	0.020	0.077	0.288***	0.088
EASY	-0.182	0.317	0.554*	0.288	-0.343	0.397
PRIV	-0.11**	0.045	-0.061	0.041	-0.099**	0.041
AGE	0.693***	0.112	0.471***	0.101	0.76***	0.133
AIRBUS	-1.613***	0.235	0.045	0.214	-2.309***	0.239
BOEING	-1.15***	0.178	0.466***	0.162	-1.727***	0.168
CFM	0.98***	0.166	0.168	0.151	1.42***	0.187
IAE	1.022	0.642	0.974*	0.583	1.146*	0.675
PW	0.896***	0.130	0.318***	0.118	1.126***	0.147
GE	0.245	0.164	-1.366***	0.149	0.588***	0.197
RR	0.331*	0.170	0.182	0.154	0.362*	0.193
TIME	-0.007*	0.004	0.014***	0.003	-0.012***	0.005
Intercept	-	-	-	-	-5.564***	0.549
R^2	0.95		0.96		0.97	
Observations	310		310		310	

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

† = Fixed effect panel data model; †† = Random effect panel data model

The estimates related to Model #2, where we focus only on aggregated pollution levels, are pretty similar to those of Model #1, but with some important differences. Again, aircraft movements and aircraft size have a positive and significant effect on *LAP*: the former elasticity is +1.06%, while the latter is +0.74%. Hence, the magnitude is lower than in Model #1. *Ryanair* has no effect on pollution, as well as *easyJet* (the statistically significance is too low). There is no private ownership effect while the fleet age elasticity is now equal to +0.47% (again a lower magnitude). *Airbus* has no effect on pollution while *Boeing* manufactured aircraft increase total pollution levels. Aircrafts with *PW* engines increase pollution, while those with *GE* engines give rise to lower level of pollution. The results for noise levels (Model #3) are similar regarding aircraft movements and aircraft size (with elasticities respectively equal to +1.00% and +2.02%), *Ryanair* increases noise costs (as described before), while *easyJet* has no effect. Airports with private ownership have lower noise levels. Technical progress effect yields lower noise levels. In all regressions the goodness of fit, given by the index R^2, is high, very close to 1.

We consider model specification and performed the mis-specification tests regarding models #1-#3. 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 (i.e., the panel features are not considered) and the random effect model, where individual effects are random. Hence, we perform for each investigated model two tests: the first test compares the fixed effect model and the Pooled OLS one and the null hypothesis H_0 is such that the latter is the true model. The test is based on a F-statistic, and the null hypothesis is rejected if the P-value is lower than 0.05. The second test is the Hausman test, comparing the fixed effect and the random effect models and the null hypothesis is such that the latter is true. The Hausman test is based on a χ^2-statistics and the null hypothesis is rejected if the P-value is lower than 0.05. In models #1-#2 the null hypothesis is always rejected, while it is not possible to reject it in model #3 in the comparison between the fixed and the random panel data models. As a result, estimates presented for model #3 in Table 6 are obtained with the random effect panel data model, Swamy-Arora specification.

7.1 Sensitivity analysis

In order to check for the robustness of our econometric results we have performed a sensitivity analysis, taking into account different weights for the different pollutants and for the unit noise level. As discussed before we control for the robustness of our empirical evidence by regressing models #4-#10; in each of these models there is a different specification for the weights of the different pollutants (two specifications, a lower bound – model #4 and an upper bound – model #5) and for the unit noise levels (four specifications, a lower bound unit noise level provided by Schipper – model #6 and 4 unit levels presented by Dings et al. (2003) – models #7-#10). Table 7 shows the output of these different models. Model #1 is reported for comparison.[33] The changes in the estimated coefficients are highlighted in bold. It is evident that most of the estimated coefficients do not change both sign and statistical significance. The only impact of these alternative measures is to modify the magnitude, as expected. This implies that in order to apply the econometric model to a specific airport – as in the case of a cost-benefit analysis –it is necessary to adopt monetary weights (for pollutants and noise) appropriate to the specific conditions. However, there is also a very small number of changes in the statistically significance of the estimated coefficients, but this regards only two brands of engine manufacturers – namely, General Electric (GE) and Rolls-Royce (RR). The latter variable becomes statistically significant in models #5-#9, while the former in models #4 and #10. In addition, in model #7 – i.e., the one with a very low value of unit noise level – GE has a statistically significant estimated coefficient with a different sign than in model #1 (where it is not significant). Last the evidence regarding general technical progress – given by the variable TIME – becomes statistically significant at the 95% in models #4 and #10.

To sum up, Table 7 seems to provide enough evidence that the results presented in Table 6 are robust to different specification of pollutants weights and unit noise levels.

[33] The standard errors are omitted for shortness (but they are available upon request).

Table 7: Econometric models for robustness checks

	Econometric Model							
	Model #1	Model #4	Model #5	Model #6	Model #7	Model #8	Model #9	Model #10
		LAP lower bound	LAP higher bound	Schipper lower bound	Dings #1	Dings #2	Dings #3	Dings #4
Indep. Variables	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
ATM	1.054***	1.055***	1.053***	1.051***	1.046***	1.049***	1.053***	1.057***
MTOW_ATM	1.806***	1.87***	1.713***	1.697***	1.477***	1.625***	1.791***	1.905***
RYAN	0.21**	0.224**	0.192**	0.185**	0.137**	0.168**	0.207**	0.235**
EASY	-0.182	-0.211	-0.138	-0.131	-0.012	-0.094	-0.175	-0.226
PRIV	-0.11**	-0.114**	-0.106***	-0.105***	-0.094***	-0.101***	-0.11**	-0.115**
AGE	0.693***	0.74***	0.635***	0.613***	0.492***	0.568***	0.681***	0.778***
AIRBUS	-1.613***	-1.753***	-1.428***	-1.379***	-0.958***	-1.234***	-1.579***	-1.846***
BOEING	-1.15***	-1.272***	-0.983***	-0.944***	-0.563***	-0.814***	-1.12***	-1.35***
CFM	0.98***	1.057***	0.877***	0.861***	0.653***	0.789***	0.963***	1.101***
IAE	1.022	1.067	0.968*	0.969*	0.904*	0.942*	1.014	1.087
PW	0.896***	0.941***	0.832***	0.827***	0.696***	0.783***	0.886***	0.961***
GE	0.245	**0.35****	0.101	0.066	**-0.271****	-0.047	0.219	**0.417****
RR	0.331*	0.331*	**0.328****	**0.33****	**0.318*****	**0.327****	**0.331****	0.329*
TIME	-0.007*	**-0.009****	-0.005	-0.004	0.0004	-0.003	-0.007*	**-0.01****
R^2	0.95	0.94	0.96	0.96	0.97	0.97	0.95	0.94
Observations	310	310	310	310	310	310	310	310

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

The last part of our robustness analysis is related to the determinants of environmental effects taking into account that part of them are already internalized at the airport level, mainly through noise limitations. Table 8 presents the econometrics results when the dependent variable is the aggregate environmental effects with variable weights based on airport location (due to regulation) (model #11) and when it is only the noise level (model #12). The two models are compared with our baseline model for aggregate airport environmental effects (model #1) and for airport noise level (model #3). The two latter models do not take into account of any internalization activity based on regulation. Any significant change is highlighted in bold and provides some insights on the possible impacts on the determinants of airport environmental effects of regulation. We find that all results are confirmed with the following exceptions: (1) the magnitude of the coefficients is generally lower; (2) the dummy *RYAN* is not significant in the aggregate environmental effect equation if we take internalization into account, (3) there is a change in the significance of the dummy GE engine, with a negative sign. Hence, imposing variable weights due to noise regulation may effectively reduce impacts of factors affecting airport environmental effects, since the magnitude of determinants is lower. This means that the higher weights assigned to noise in airports in urban areas is more than compensated by the lower noise weight in airports in rural areas. This is important for considering the factors affecting pollution in a national system but also to appreciate differences in specific airports. The same insights are obtained if only annual noise levels are considered (model #12), with the additional evidence that private airports have no longer a significant effect.

Table 8: Determinants of not internalized environmental effects

	Econometric model					
	Model #1	Model #11		Model #3	Model #12	
	Dep. Variable: TE_WEI				Dep. Variable: NOISE_WEI	
Indep. Variables	Coeff.	Coeff.	S.E.	Coeff.	Coeff.	S.E.
ATM	1.054***	1.018***	0.009	1.001***	1.027***	0.015
MTOW_ATM	1.806***	1.125***	0.046	2.024***	1.339***	0.078
RYAN	0.21**	**-0.049**	0.038	0.288***	**0.021**	0.063
EASY	-0.182	-0.075	0.142	-0.343	-0.257	0.238
PRIV	-0.11**	-0.042**	0.020	-0.099**	**-0.001**	0.034
AGE	0.693***	0.388***	0.050	0.76***	0.594***	0.084
AIRBUS	-1.613***	-0.981***	0.105	-2.309***	-1.703***	0.176
BOEING	-1.15***	-0.484***	0.080	-1.727***	-1.100***	0.133
CFM	0.98***	0.603***	0.074	1.42***	1.018***	0.125
IAE	1.022	**0.534***	0.287	1.146*	**0.500**	0.481
PW	0.896***	0.423***	0.058	1.126***	0.626***	0.098
GE	0.245	**-0.322*****	0.073	0.588***	0.334***	0.123
RR	0.331*	**0.061**	0.076	0.362*	0.134	0.127
TIME	-0.007*	-0.006***	0.002	-0.012***	-0.017***	0.003
R^2	0.95	0.99	-	0.97	0.97	-
Observations	310	310		310	310	

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

8. Policy and management implications

The results obtained with the econometric analysis identify the factors affecting airports' externality levels. However, they also provide the base for designing some aviation policies yielding incentives to airports' and airlines' managers to adopt more environmentally friendly choices, and to draw some interesting implication for airport management having to consider the possible environmental effects of expansion plans.

The policies may be effective since they could be linked to airport charges, and may add new elements to the current specifications of noise and emission charges. These new items are (1) a unique tariff for the aggregate environmental effects of a flight departing or landing in a specific airport – rather than two separated charges for emissions and noise that may also yield contrasting incentives, (2) a premium/penalty scheme for some crucial determinants of total environmental levels, such as the aircraft size and age. These policies do not consider the possible interaction between noise and pollution regulation that may induce a trade-off between these two environmental effects. However, they are related to aggregate environmental effects and so the impact of this trade-off is limited.

It is possible to draw two different models of airport charges including environmental effects: with the first model, using the estimated elasticities, we compute the charge for some additional aviation activities in airports, e.g., an additional flight, an increase in the aircraft size per movement, an increase in the fleet average age; under the second model, using the sign of the factors that significantly affect the environmental levels, it is possible to model prizes and penalties in presence of activities connected to these factor, e.g., discriminating flights according to aircraft of engine manufacturers.

First, we describe the policy implications based on the estimated elasticities. In Model (1) the elasticity for aircraft movements is +1.054%. This implies that a +1% in yearly movements generates a +1.054% in total environmental levels. The annual average movements in the representative airport of the sample is equal to 37,475.99 movements, so that a +1% corresponds to 374.76 additional movements. The average total environmental level in the representative airport – using the monetary weights adopted in Models (1)-(3) is equal to euro 6,391,698, so that a +1.054% is equal to euro 67,368.5. By dividing the latter for the 374.76 additional movements we get a per-movement tariff equal to euro 179.76.

The same procedure can be applied to design a tariff not on flights but on aircraft size per movement, measured in MTOW. The estimated elasticity is +1.806%. The average MTOW per movement is equal to 56.98 tonnes, so that a +1% increase in the average size per movement is equal to 0.5698 tonnes, while a +1.806% of the total environmental level in the representative airport – expressed in euro – is equal to euro 115,434.1. This implies that an increase in the average fleet size equal to 1 MTOW leads to an increase in the yearly environmental effects – expressed in monetary values – equal to euro 202,587. Hence, the total annual charge for the representative airport – having a average MTOW per flight equal to 56.98 tons – is given by euro 202,587 times 56.98 tons = euro 11,543,407, which has to be shared (proportionally to the MTOW share over the year) among all the airlines operating in the airport. This result can be also interpreted as a per movement charge of ±5.4 euro/ton that is equal to euro 308.02 in the case of the average aircraft of 56.98 tons.

Regarding age, the estimated elasticity is +0.693%. The latter clearly is based on certification data, which do not exactly represent aircraft ages: a model could receive certification in a specific year but then an aircraft of that model could be delivered some year later, being much younger. We do not capture this effect, but we get the technological level embedded in a aircraft model that receive certification in a specific year. Hence our age elasticity is a measure of updated or new models, capturing part of technical progress. The average fleet age in the representative airport is 17.98 years per aircraft; hence a +1% in aircraft age is equal to 0.1798 years. The latter gives rise to an increase of euro 44,294.47 in total environmental levels (i.e., 0.693% of euro 6,391,698). By dividing the latter for 0.1798 we get euro 246,354.4, which is the amount that should be applied to the fleet for each year in its average age. For instance, if the average aircraft age in the fleet of the representative airport is almost 18 years, the annual charge should be equal to euro 4,429,447. The latter has to be divided among the airlines operating in the airport, according to their contributions to the average fleet age. This result can be also interpreted as a per movement charge of ±6.57 euro-per-year-of-age of the aircraft, that is equal to euro 118.19 in the case of the average aircraft age of 17.98 years.

Following the same reasoning it is possible to estimate the amount of environmental effects generated by the construction of a new runway: if the plan is to have it in order to manage about 10,000 more movements per year, this implies a total environmental effect equal to about euro 179.76 per movement times 10,000 movements, i.e., euro 1,797,600 per year, which has to be included in the costs-benefits analysis.[34]

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[34] Notice that we are referring to the amount of total environmental effects produced by the increased traffic allowed by the construction of a new runway evaluating airports, on average, on the basis of the coefficients we have estimated. We do not take into account the population because this would imply to consider the social costs and this in turn means to change the weights imposed to the different pollutants and to the noise on the basis of the population density, of the aircraft trajectories, and of other geographical specificities. Obviously, this would require a much more complicated analysis more oriented to investigating the social effects rather than the determinants of noise and local air pollution.

The econometric estimates obtained in the previous Section may shed some lights also on managerial decisions in case of airport expansion, with the aim of minimizing the possible environmental effects. For instance, the latter are lower whether airport managers choose to increase the flight frequency or if they go for keeping the number of flights fixed and increase the aircraft size? We analyze this issue by observing two examples of Italian airports, Bergamo and Rome Fiumicino, which have increased their number of passengers during the last period. Bergamo has increased its annual passengers from 6,482,590 in 2008 to 10,404,625 in 2015 (+60%), while Fiumicino has a +15% increase in the same period (from 35,226,351 in 2008 to 40,463,208 in 2015). We analyze two scenarios: first we observe the predicted increase in aggregate environmental effects if the required extra-capacity is met by increasing the flight frequency, while keeping all the other variables included in Model #1 fixed. In the second scenario, we augment the aircraft size (i.e., we increase the MTOW) to address the additional capacity while keeping all the other variables (including flight frequency fixed).

If Bergamo airport management choose to increase the frequency they get a predicted aggregate annual environmental effects equal to € 15,079,398, with an increase with respect to the 2008 level by +57%. If managers choose instead to increase aircraft size the predicted increase is much larger, equal to +124%. Similar results are obtained for Rome Fiumicino. If airport managers choose the first scenario (i.e., to increase flight frequency), the percentage increase in annual environmental effect is equal to +10%, while if they address the required additional capacity by increasing aircraft size the percentage increase is +22%. Hence from these examples we obtain that airport management should address the additional capacity by increasing frequency rather than size. Clearly, this result depends upon a number of factors such as the current level of the other variables (e.g., the aircraft age, the percentage of *easyJet* and *Ryanair* flights, etc.) that may change over time and lead to different results. However, the interesting implication of our empirical investigation is that airport managers can obtain predicted levels of annual environmental effects and analyze which combination of their determinants may not harm excessively the environment..

9. Conclusions

In this contribution we study the factors that may affect the total (i.e., pollution and noise together) and separated environmental effects produced by airports in their aviation activities. The aim is to investigate whether some characteristics of airports and airlines choices affect the environmental levels, and to provide some estimates of the impact of these factors. We investigate a sample of 31 Italian airports, for the period 1999-2008, and apply a panel data econometric model.

We provide evidence that a 1% increase in airport's yearly movements yields a 1.05% increase in total environmental levels, a 1% in aircraft's size (measured in MTOW) gives rise to a 1.81% increase in total effects and a 1% increase in aircraft age generates a 0.69% increase in enviromental levels. Other factors affecting environmental effects are the share of *Ryanair* and *easyJet* aircraft movements. Similar determinants but with lower magnitude are observed if we take into account that a portion of the airport environmental effects are already internalized at the airport, through noise regulation such as constrained flight paths.

Our policy implications are that the tariff internalizing the total amount of externalities produced is about euro 180 per flight, while the tariff limiting only pollution is about euro 60 and the one reducing noise is about euro 110. Moreover, we have also analyzed airport management implications if they have to address additional capacity: from our examples we get that increasing flight frequency is more environmental friendly than augmenting the aircraft size.

The analysis can be extended to consider all the currently operating commercial aircraft fleet, and possible interactions between aircraft and engine manufacturers. Moreover, it will be interesting to investigate the embedded effect of technical progress on aviation environmental effects, by taking into account the impact of updated models over time. Last, another extension may be to include the demand pattern as a possible determinant of aggregated airport environmental effects, since its magnitude should be relevant in cost-benefit analyses. This is left for future research.

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Appendix

Table A1, List of Italian airports in the sample

Airport	IATA Code	Aircraft Movements (2008)	Passengers Movements (2008)	Private	Airport	Code	Aircraft Movements (2008)	Passengers Movements (2008)	Private
Alghero	AHO	13,844	1,383,296	No	Milan Malpensa	MXP	212,841	19,014,186	No
Ancona	AOI	12,518	406,292	No	Naples	NAP	60,448	5,594,043	Yes
Bari	BRI	29,362	2,465,539	No	Olbia	OLB	18,323	1,739,619	Yes
Bergamo (Milan)	BGY	61,980	6,482,590	No	Palermo	PMO	47,120	4,424,867	No
Bologna	BLQ	56,993	4,124,298	No	Pescara	PSR	6,556	396,188	No
Brescia	VBS	9,723	253,598	No	Pisa	PSA	37,887	3,940,490	No
Brindisi	BDS	11,321	967,546	No	Reggio Calabria	REG	7,160	491,302	No
Cagliari	CAG	33,824	2,924,805	No	Rimini	RMI	5,381	417,879	No
Catania	CTA	56,704	6,020,606	No	Rome Ciampino	CIA	51,275	4,778,059	Yes
Crotone	CRV	1,327	89,330	No	Rome Fiumicino	FCO	340,971	35,226,351	Yes
Florence	FLR	35,305	1,926,837	Yes	Turin	TRN	48,797	3,402,047	No
Forlì	FRL	6,274	772,078	No	Treviso	TSF	13,651	1,697,720	Yes
Genoa	GOA	18,322	1,170,163	No	Trieste	TRS	14,731	776,757	No
Lamezia Terme	SUF	14,076	1,495,421	No	Venice	VCE	73,744	6,848,244	Yes
Lampedusa	LMP	3,326	208,567	No	Verona	VRN	36,362	3,366,766	
Milan Linate	LIN	96,823	9,264,561	No					

Table A2. Weights to noise and pollution taking into account airport internalization and population density

Airport	Airport location	Weight for noise of a flight	Airport	Airport location	Weight for noise of a flight
Alghero	Medium	324	Milan Malpensa	Medium	324
Ancona	Rural	150	Naples	Urban	600
Bari	Medium	324	Olbia	Rural	150
Bergamo	Urban	600	Palermo	Rural	150
Bologna	Urban	600	Pescara	Rural	150
Brescia	Rural	150	Pisa	Medium	324
Brindisi	Rural	150	Reggio Calabria	Rural	150
Cagliari	Medium	324	Rimini	Rural	150
Catania	Medium	324	Rome Ciampino	Urban	600
Crotone	Rural	150	Rome Fiumicino	Medium	324
Florence	Medium	324	Turin	Medium	324
Forlì	Medium	324	Treviso	Rural	150
Genoa	Rural	150	Trieste	Rural	150
Lamezia Terme	Rural	150	Venice	Medium	324
Lampedusa	Rural	150	Verona	Rural	150
Milan Linate	Urban	600			

Table A3: Descriptive statistics of variables included in the analysis

Variable	Mean	St. Dev.	Min	Max	Description
TE	6,391,698	12,507,493	9,904	66,024,454	Euro
LAP	2,206,694	4,245,695	592	24,411,155	Euro
MAN	4,185,004	8,284,341	7,203.09	43,334,427	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.
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 A4: Descriptive statistics of different pollution and noise specifications

Variable	Mean	St. Dev.	Min	Max	Description
LAP_low	1,562,740	3,022,642	419	17,411,959	Euro
LAP_high	3,285,109	6,285,391	883	36,056,925	Euro
Schipper_low	2,557,502	5,062,653	4,402	26,482,150	Euro
Dings_1	1,162,501	2,301,206	2001	12,037,341	Euro
Dings_2	1,937,501	3,835,343	3,335	20,062,235	Euro
Dings_3	3,875,003	7,670,686	6,670	40,124,469	Euro
Dings_4	7,750,006	15,341,371	13,339	80,248,938	Euro

Table A5: Kendall correlation indices

	TE	*MAN*	*LAP*	*ATM*	*AGE*	*RYAN*	*EASY*	*PRIV*	*AIRBUS*	*BOEING*	*CFM*	*IAE*	*PW*	*GE*	*RR*	*MTOW*	*MTOW_ATM*
TE	1.00	0.97	0.93	0.87	0.14	-0.22	0.28	0.23	0.49	-0.01	0.05	0.53	-0.12	0.38	0.36	0.93	0.29
MAN		1.00	0.90	0.87	0.13	-0.22	0.27	0.22	0.47	-0.02	0.05	0.52	-0.12	0.38	0.36	0.91	0.28
LAP			1.00	0.88	0.14	-0.24	0.30	0.25	0.52	0.00	0.06	0.55	-0.12	0.36	0.38	0.97	0.29
ATM				1.00	0.11	-0.26	0.28	0.22	0.47	-0.12	-0.01	0.52	-0.09	0.41	0.35	0.89	0.17
AGE					1.00	-0.48	-0.05	0.09	0.16	0.15	-0.23	0.21	0.27	-0.12	0.16	0.14	0.15
RYAN						1.00	-0.03	-0.14	-0.19	0.12	0.33	-0.35	-0.24	-0.03	-0.18	-0.24	0.02
EASY							1.00	0.27	0.31	-0.01	0.22	0.22	-0.24	0.25	0.22	0.30	0.15
PRIV								1.00	0.22	0.07	0.08	0.12	-0.13	0.10	0.13	0.25	0.18
AIRBUS									1.00	-0.04	0.23	0.47	-0.18	0.18	0.25	0.52	0.36
BOEING										1.00	0.32	0.03	-0.10	-0.21	-0.01	-0.02	0.49
CFM											1.00	-0.02	-0.63	-0.05	0.01	0.06	0.36
IAE												1.00	0.02	0.20	0.31	0.54	0.28
PW													1.00	-0.15	-0.09	-0.13	-0.27
GE														1.00	0.17	0.37	0.01
RR															1.00	0.37	0.11
MTOW																1.00	0.29
MTOW_ATM																	1.00