Transport and Telecommunication, 2014, volume 15, no 1, 20–26
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia
DOI 10.2478/ttj-2014-0003

SPATIAL ASPECTS OF EUROPEAN AIRPORTS' PARTIAL FACTOR PRODUCTIVITY

Dmitry Pavlyuk

Transport and Telecommunication Institute
Lomonosova 1, Riga, LV-1019, Latvia
Ph.: (+371) 29958338. E-mail: Dmitry.Pavlyuk@tsi.lv

This research is devoted to discovering of spatial effects in European airports' partial factor productivity (PFP). A set of study PFP indicators includes infrastructural (air transport movements per runway), labour (workload units per employee), and financial (revenue and profit per workload unit) ratios. We utilised a number of appropriate statistical tests (Moran's I., Geary's C., Mantel test, and spatial auto-regression) for revelation of spatial relationships between PFP indicator's values. The tests were separately applied to samples of Spanish (2009–2010) and UK airports (2011–2012) and provided evidences of significant spatial effects in data.

Keywords: airport, partial factor productivity, spatial heterogeneity, spatial dependency, spatial statistics

1. Introduction

During the last two decades estimation of airport efficiency became a point of attention both for practitioners and academic researchers [1], [2]. After legislative liberalisation of EU air transportation market, airport industry began transforming from a historical form of natural monopolies to free market. Efficiency is one of the key requirements for a company acting in a competitive environment, and estimates of airport efficiency become important for airport management, industry regulators, and other stakeholders.

Airport efficiency measurement is not a straightforward task due to a complex structure of airport business. A common definition of efficiency (as a ratio of the useful output to the total input) requires setting of airport's output and inputs, which are very diverse. A set of outputs of an airport includes both technical and financial components. Technical outputs includes served flights (air transport movement, ATM), carried passengers (air passenger movement, PAX), loaded cargo, and others (e.g. served passengers and cargo are usually combined into workload units, WLU). Financial outputs include revenue (split to aeronautical and non-aeronautical), costs, profit (e.g. in form of earnings before interest, taxes, depreciation, and amortization, EBITDA), and others. Inputs of an airport are also very heterogeneous – infrastructural (runways, terminals, surface), labour (employees), financial (expenses).

Partial factor productivity (PFP) indexes are one of the simplest tools of efficiency estimation. A PFP index is generally constructed as a simple ratio of a particular output to a particular input (for example, a yearly number of carried passengers per runway). Some financial ratios (like a ratio of revenue to employment cost) also can be considered as PFP indicators. PFP indexes reflect efficiency of specific aspects of airport activity and don't represent the whole picture. Nevertheless, simplicity of PFP indexes makes them very attractive and frequently used tool. PFP indexes are used in many recent researches of airport efficiency both as a primary([3–5]) and complementary tool.

An extensive development of European airline network during later 1990s [6] has been affecting EU airports' business substantially. Nowadays airports cannot be analysed as independent units, but multi-way interactions between neighbour airports should be taken into account. Significant relationships between characteristics of geographical neighbours are widely acknowledged in the regional science [7], but, to best of our knowledge, there are no systematic studies of spatial effects in airport productivity. Omitting of liable spatial effects can lead to serious problems with analysis and interpretation of estimates of airport efficiency, but then spatial structure of airport industry can provide additional essential information on this topic.

Development of spatial statistics provided excellent tools for analysis of spatial effects in data[8]. There are many developed statistical tests, which allow discovering spatial relationships of different kinds. In this research we apply those tests to discover probable spatial effects between PFP indicators of airport efficiency for a sample of UK and Spanish airports.

2. Airports' Partial Factor Productivity

The research data set includes information about following parameters of UK and Spanish airports:

- Air transport movements (ATM) served by an airport;
- Passengers carried (PAX) by an airport;
- Workload units (WLU) served by an airport;
- Number of airport's terminals;
- Number of airport's runways;
- Airport's revenue;
- Airport's EBITDA;
- Airport's employment costs.

Data on traffic flows (ATM, PAX, WLU) is collected from the Eurostat Database [9] (some observations were supplemented with data from bodies of national statistics). Indicators of airport infrastructure (terminals, runways) are collected from airport official reports.

Collecting values of financial indicators is one of the most problematic areas of airport efficiency research. Firstly, approaches to calculation vary for different countries and even for different airports within the same country. Secondly, values of financial indicators require transformation to be comparable between countries. Finally, some airports can be managed by the same operator, and data is provided to the public in a consolidated form only.

In this research we collected financial data on UK airports directly from their annual reports for 2011 and 2012 years. The UK airports subsample includes 49 airports, and full financial data are available only for 21 of them.

Financial data of Spanish airports was collected from the auditor's report [10], provided by Spanish airports operator (AENA). The Spanish airports subsample includes 48 airports with full financial information about 46 of them. Information for Spanish airports is available for 2009–2010 years only.

Summary statistics of the research sample are presented in the Table 1.

Table 1. Data set descriptive statistics. Source: author's calculations

	ATM, number of flights	WLU, number of workload units	PAX, number of passengers carried	Revenue, thousand euro	EBITDA, thousand euro	Employee cost, thousand euro
Spanish airports 2009						
Min	1419	6228	6228	165	-6190	817
Median	13129	1040443	1040374	8829	393	4336
Mean	40758	4043217	4041918	40131	14330	7472
Max	427168	47976523	47943507	590369	219501	52176
Spanish airports 2010						
Min	1243	5906	5906	21	-6411	761
Median	12561	980307	980252	8470	21	4522
Mean	40371	4168557	4167065	41384	14925	7620
Max	426941	49837683	49797635	614076	247171	52810
UK airports 2011						
Min	10	57	493	2895	332	2735
Median	10171	413870	413837	63559	26376	14169
Mean	41204	4472293	4467158	224348	98071	44977
Max	476293	69545035	69388105	2456000	1207000	314000
UK airports 2012						
Min	63	250	445	3128	-733	4151
Median	9405	601553	601550	84064	28197	23224
Mean	40662	4503164	4498009	276823	113267	61551
Max	471452	70139072	69983473	2718000	1237000	356000

Selection of UK and Spanish airports for this research is substantiated by significant differences in economic environments and airport industry organisation (including spatial) in these countries.

UK airports are generally concentrated in the North West of the country, in area with higher population density and economic activity. After a set of airport sales and acquisitions, initiated by UK Competition Commission, airports are generally managed by of different operators (M.A.G., Heathrow Airport Ltd., Stansted Airport Ltd., Gatwick Airport Ltd., and London Luton Airport Operations Ltd.). Different operators are supposed to act as competitors, enforcing economic efficiency of each other. Government regulation of UK airports is implemented on the base RPI-X approach[11].

Economic environment of the airport industry in Spain is significantly different. Almost all Spanish airports are managed by one operator (AENA), which obviously has an extensive market power. Spatial patterns of Spanish airport also significantly differ from UK one. Besides the main airport (Madrid Barajas), where traffic flows are considerably explained by economic activity, there are a wide range of airports, generally served tourist flows and located near the seaside (or on islands).

We chose these two subsamples of EU airports to test presence of spatial effects in different economic and spatial settings.

For research purposes a number of PFP indicators were calculated. The final list of indicators includes:

- ATM per runway;
- WLU per employee cost;
- Revenue per WLU;
- Revenue per ATM;
- EBITDA per WLU;
- EBIDTA per revenue.

Summary statistics of PFP indicators' values are presented in the Table 2.

Table 2. Summary of PFP indicators. Source: author's calculations

	ATM per Runway	WLU per Employee Cost	Revenue per WLU	Revenue per ATM	EBITDA per WLU	EBITDA per Revenue
Spanish airports 2009						
Min	1419.00	5.56	4.96	14.59	-270.87	-10.21
Median	12966.00	239.72	9.24	748.07	0.45	0.04
Mean	25158.00	278.85	13.93	648.38	-24.53	-1.26
Max	106792.00	919.51	97.46	1607.52	5.40	0.59
Spanish airports 2010						
Min	1243.00	4.10	5.77	14.64	-343.48	-11.65
Median	12408.00	214.21	9.48	750.40	0.35	0.03
Mean	25145.00	274.80	14.49	663.70	-32.39	-1.32
Max	106735.00	943.72	75.34	1617.43	5.49	1.00
UK airports 2011						
Min	629.50	15.50	2.23	290.10	0.59	0.05
Median	43769.80	324.20	14.59	1417.80	5.60	0.34
Mean	53523.60	307.20	22.07	1679.20	5.62	0.33
Max	158764.30	527.00	152.59	5156.50	17.36	0.67
UK airports 2012						
Min	3634.00	88.64	2.93	383.90	-1.06	-0.06
Median	51045.00	238.05	15.06	1431.80	4.87	0.31
Mean	59291.00	263.54	16.84	1676.40	5.42	0.32
Max	157151.00	513.39	38.75	5765.20	17.64	0.71

Comparison of PFP indicators' values of UK and Spain airports are presented on Figure 1 in a form of box plots.

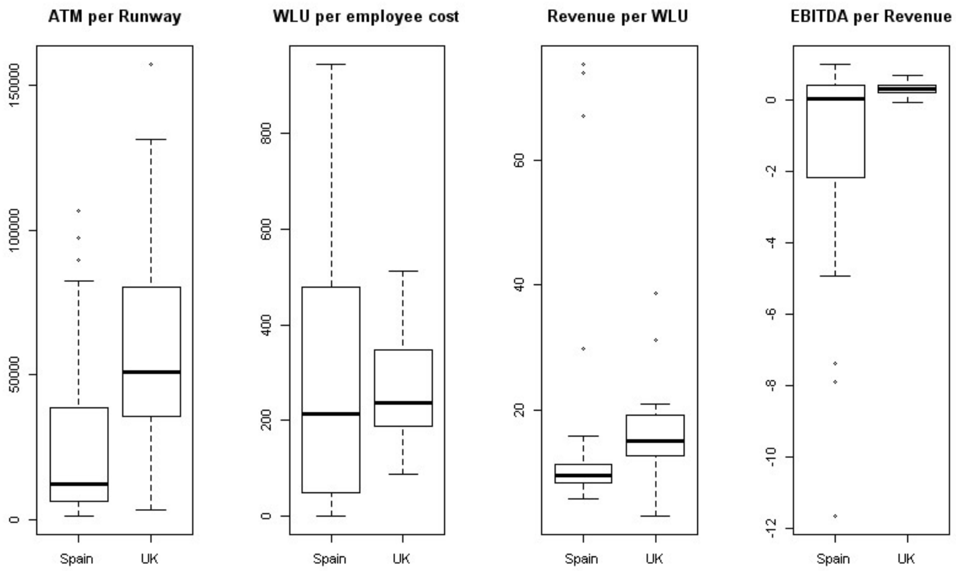

Figure 1. Box plots of UK and Spanish airport PFP indicators. Source: author's calculations

The box plots support our assumption about significant differences in performance of UK and Spanish airports. Loading of airports' infrastructure (ATM per runway) is significantly higher in UK airports; technical performance of employment (WLU per employee cost) is similar in both countries, but has larger variance within Spanish airports subsample. Revenue PFP (revenue per WLU) indicates higher financial performance of UK airports, but with higher variance between them. The most significant difference between two subsamples is indicated by EBIDTA per revenue financial ratio. A significant share of Spanish airports provided negative values for EBITDA. These financial losses are explained by reduction of airline tourists flows after the world crisis, and a high level of dependence between these flows and Spanish airports activity (and economy of Spain in general).

Also we note that there are a set of possible outliers in the sample – a problem to deal with in further statistical analysis.

3. Spatial Effects in Airports' PFP Values

Values of all used PFP indicators are non-uniformly distributed over the geographic space. Patterns of spatial distribution vary between indicators (see Fig.2 for a spatial distribution of revenue per WLU indicator).

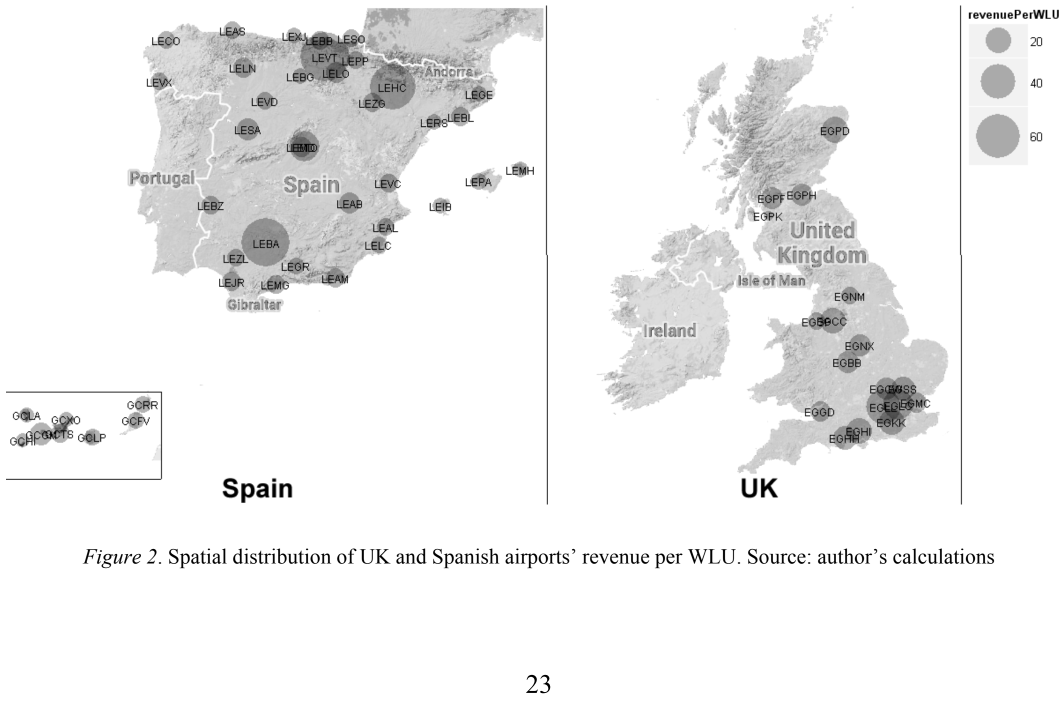

Figure 2. Spatial distribution of UK and Spanish airports' revenue per WLU. Source: author's calculations

We applied the following statistical procedures to discover spatial relationships between values of selected PFP indicators:

- Moran's I test;
- Geary's C test;
- Mantel test;
- Spatial auto-regression.

All used approaches are well-known in spatial data analysis and their formal description can be found in literature (e.g., [12], [13]).

All specified tests require predefined information about spatial structure of research parameters. Generally a proximity of i and j units are defined by a spatial weight w_{ij}. Specification of spatial weights assumed that units with higher values of spatial weights are more closely related. Conventionally, spatial weights w_{ii} (proximity of a unit with itself) are set to 0. There are a wide range of approaches, which can be used to define spatial weights. For example, spatial weights can be defined as an inverse geographical distance between objects, inverse travel times and costs. In this research we use a simplest form of spatial weights – inverse geographical distances between airports (with a linear distance decay). Realising all shortcomings of this specification, we found it sufficient for the goal of this research – discovering presence of spatial relationships. If spatial effects will be discovered under this specification of spatial weights, their presence will be highly probable under more careful (and complicated) specification.

There are two possible sources of spatial effects widely acknowledged in regional science. The first type of spatial effects (the so-called spatial heterogeneity) is based on factors, common for a geographic area. For airports these factors can include economic activity of a region, population density, weather conditions, and others. These factors are distributed non-uniformly over the space (for example, concentrated economic activity in Great London area or attractiveness of Spanish sea-side and islands as tourist destinations), which affect values of PFP indicators. Spatial heterogeneity usually leads to a positive spatial correlation.

The second type of spatial effects (called spatial dependency) is explained by interrelation between neighbour airports. This relationship can be two-directional – negative (e.g. competition between neighbour airports for traffic flows) or positive (direct or indirect collaboration of neighbour airports). Separation of these two types of spatial effects is a very important practical task, lying outside of this research's scope. All statistical tests we applied to the research samples are designed to discover aggregate spatial effects, which can be a problem in case of different direction of spatial interactions between airports. This fact decreases the power of the tests (increases Type II errors), but doesn't affect their significance. So if statistically significant spatial effects will be discovered, we can conclude their presence, but if spatial effects will be found as not significant, additional research on their structure will be required before a conclusion of their absence.

All 4 subsamples (Spanish airports 2009–2010, and UK airports 2011–2012) have possible outliers – airports, which show significantly different PFP values (according to the box plots above and standard z-scores). We run all tests in two versions – with and without filtering of outliers. Estimation results of spatial test statistics (Moran's I., Geary's C., and spatial auto-regression) with filtered outliers are presented in the Table 3.

Table 3. Results of statistical tests for spatial dependency. Source: author's calculations

	ATM per runway	**WLU per employee cost**	**Revenue per WLU**	**Revenue per ATM**
Spanish airports 2009				
Moran's I	-	-0.262*** (0.006)	0.072** (0.043)	-0.193* (0.055)
Geary's C	1.336*** (0.019)	1.496*** (0.000)	1.258* (0.100)	1.254** (0.016)
SAR	-	-	0.035** (0.013)	-0.031** (0.032)
Spanish airports 2010				
Moran's I	-	-0.257*** (0.007)	0.111*** (0.002)	-0.209** (0.035)
Geary's C	1.306** (0.031)	1.486*** (0.000)	1.471** (0.015)	1.286*** (0.007)
SAR	-	-	0.035*** (0.004)	-0.032** (0.027)

The continuation of Table 3

UK airports 2011				
Moran's I	0.104** (0.012)	0.093** (0.036)	0.156*** (0.002)	0.103*** (0.009)
Geary's C	-	-	-	-
SAR	0.049* (0.062)	-	0.050** (0.031)	0.045* (0.089)
UK airports 2012				
Moran's I	0.067* (0.063)	-	0.083** (0.025)	-
Geary's C	-	-	-	-
SAR	-	-	0.046** (0.045)	-

***, **, * – significant at 1, 5, and 10% level accordingly; insignificant values are excluded (–).

Statistically significant spatial effects are discovered for different PFP indicators and in different subsamples. A sign (direction) of spatial correlation for some PFP indicators is not stable over subsamples.

ATM per runway has a weak negative spatial autocorrelation for Spanish airports' subsamples (according to Geary's C., sensitive to local spatial relationships) and a weak positive value for UK airports (according to global Moran's I. test). Distinction of these results can be explained by different spatial patterns of UK and Spanish airports, but requires additional research for a detailed conclusion.

Technical performance of employment costs (WLU per employee cost) has highly significant negative spatial autocorrelation for Spanish airports (both for Moran's I. and Geary's C. tests). Technically speaking, this result means that stronger neighbour airports (with higher value of WLU per employee cost indicator) negatively affect a value of this indicator in a given airport. These effects present for Spanish airports and absent for UK airport subsamples. Economic interpretation of these negative spatial effects (for example, competition between airports for employment) is also a matter of further research and discussion.

The most consistent results are received for value of revenue per WLU indicator. The indicator's values show significant positive spatial autocorrelation for all 4 subsamples. These results can be explained by spatial heterogeneity (concentration) of economic activity and income both in Spain and UK. Note that Geary's C. tests point negative local spatial dependence.

4. Conclusions

The main goal of this research was to test presence of spatial effects in PFP values of airports. A study set of PFP indicators includes performance values of infrastructure (WLU per runway), employment (WLU per employee cost), revenue (revenue per WLU, revenue per ATM), and profit (EBITDA per WLU, EBIDTA per revenue). We applied a set of statistical tests (Moran's I., Geary's C., and Mantel test, spatial auto-regression) to discover spatial effects in 4 subsamples – Spanish airports in 2009–2010 and UK airports in 2011–2012. Selection of these subsamples is substantiated theoretically by testing of spatial effects presence in different economic and spatial environments and technically by available financial data.

Significant spatial effects were discovered in many cases; a sign of these effects differs between PFP indicators in different countries. These effects have an aggregative nature and can be explained both by spatial heterogeneity and spatial dependency. General statistical tests applied in this study don't allow distinguishing between different types of spatial effects.

Presence of statistically significant spatial effects should be included into consideration in academic and empirical airport benchmarking models. Omitted spatial effects can lead to biased estimates of airports' efficiency and incorrect interpretation of results. This study is a proof of concept; a detailed investigation of spatial effects nature and technical aspects of their estimation is considered by the author as a direction for further research.

References

1. Liebert, V., Niemeier, H. M. (2011). Benchmarking of Airports – A Critical Assessment. In Proceedings of the 12th World Conference on Transport Research (p. 46). Lisbon, Portugal.
2. Pavlyuk, D. (2012). Airport Benchmarking and Spatial Competition: A Critical Review, *Transport and Telecommunication*, 13(2), 123–137.
3. Abdesaken, G., Cullman, A. (2006). The Relative Efficiency of German Airports, presented at the GARS Amsterdam Student Workshop, Amsterdam.
4. Muller, J., Ulku, T., Zivanovic, J. (2009). Privatization, restructuring and its effects on performance: A comparison between German and British airports, German Airport Performance Project, Germany, Working Paper 16.
5. Merkert, R., Pagliari, R., Odeck, J., Brathen, S., Halpern, N., Husdal, J. (2010). Benchmarking Avinor's Efficiency, Møreforsking Molde AS, Molde, Norway, Report 1006.
6. Burghouwt, G. (2007). *Airline network development in Europe and its implications for airport planning*. England: Ashgate. 287 p.
7. Fujita, M., Venables, A., Krugman, P. R. (2001). *The spatial economy: cities, regions and international trade*. Cambridge, Mass.: MIT Press. 384 p.
8. Anselin, L. (2010). Thirty years of spatial econometrics, *Papers in Regional Science*, 89(1), 3–25.
9. Eurostat. (2013). European Statistics Database, Statistical Office of the European Communities (Eurostat).
10. TDC. (2012). Informe de fiscalización de la imputación por la entidad "aeropuertos españoles y navegación aérea" (AENA) a cada uno de los aeropuertos de los ingresos, gastos, e inversiones correspondientes a la actividad aeroportuaria, en los ejercicios 2009 y 2010. Tribunal de Cuentas, Spain, Doc 938.
11. CAA. (2011). The Airport Charges Regulations, Civil Aviation Authority, UK, Report 2491.
12. O'Sullivan, D. (2010). *Geographic information analysis*, 2nd ed. Hoboken, N.J: John Wiley & Sons. 405 p.
13. Arbia, G. (2006). *Spatial econometrics: statistical foundations and applications to regional convergence*. Berlin: Springer. 219 p.