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August 2010

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ABSTRACT

This paper is devoted to statistical analysis of spatial competition and cooperation between European airports. We propose a new multi-tier modification of spatial models, which allow estimating of spatial influence varying with the distance. Competition and cooperation effects don't diminish steadily with moving from a given airport, their structure is more complex. The suggested model is based on a set of distance tiers, with different possible effects inside each tier.

We apply the proposed modification to the standard spatial stochastic frontier model and use it to estimation of competition and cooperation effects for European airport and airport's efficiency levels. We identify three tiers of spatial influence with different completion-cooperation ratio in each one. In the first, closest to an airport, tier we note significant advantage of cooperation effects over competition ones. In the second, more distant, tier we discover the opposite situation – significant advantage of completion effects. The last tier's airports doesn't influence significantly.

In this paper we also consider some other possible applications of the proposed spatial multi-tier model.

Keywords: spatial stochastic frontier, airport efficiency, competition, cooperation

Introduction

During last few years popular "competition vs. cooperation" debates touch upon the airports sphere [1]. Before the crisis competition as the first and often the only discussion aspect was considered, but when airports met additional difficulties related with overall falling of passenger traffic, cooperation became more and more important and attracted researchers' attention.

Airport competition area is wide and various. It includes competition for passengers and for local resources between adjacent airports in overlapping of their catchment areas, competition for airlines to serve, competition between airport groups (formal or informal), and others. This research is oriented to analysis of spatial competition for passengers between adjacent airports. The situation when more than one airport serves the population is usual in Europe. It emerges as in major urban areas (London, Paris, etc) as in peripheral areas which have no airports in nearest surroundings. When some alternative airports are available for the population, competition effects appears [2].

In many cases when airports have overlapping catchment areas, cooperation effects are also occurred [3]. These effects can have different forms – formal or not. Firstly, airports operating in the same areas, can be joined to different types of alliances or even have the same owners (Heathrow and Gatwick, or Charles de Gaulle and Orly). Another very popular type of cooperation is "main airport plus satellites". Main airport serves a significant part of passenger traffic (usually international), where satellites serve special groups of customers (for example, domestic passengers or low-cost airlines). Finally, cooperation effects can appear without any formal or informal agreements between airports, but just because of their operations. Often if an airport successfully operates in a particular area, it promotes overall region development - more businesses, more tourists, better infrastructure, better transport network. As a result, adjacent airports obtain additional utility, and cooperation effects are rising.

It is obvious that both competition and cooperation effects are in place for every airports' activity area, but many researches are oriented on analysis of one aspect only (usually competition). In this research we try to both aspects simultaneously. Note that the task to separate competition and cooperation effects completely looks very difficult (if even possible), so we estimate aggregative effects on an airport and observe them for different distances from it.

The modern approach to analysis of dependences between adjacent economic units is spatial econometrics [4]. Spatial models utilise information about units' geographical locations and distances between them to estimate interacting effects. Famous Tobler's Law says "everything is related to everything else, but near things are more related than distant things", and this statement is the base for spatial models.

Usually spatial models are constructed to capture and estimate only one spatial effect (for example, competition between adjacent airports). But we believe that spatial effects are not so straightforward, and it's possible that effects of neighbours located in immediate vicinity and effects of remote neighbours are completely different, even differently directed. In this research we introduce a modification of spatial models (called *multi-tier*) and apply it to the European airports data set.

Spatial multi-tier autoregressive stochastic frontier model

Stochastic frontier model is usually presented as [5]:

$$y = f(x, \beta) + \varepsilon,$$
$$\varepsilon = v - u,$$
$$v \sim N(0, \sigma_v^2), u \geq 0,$$

Model specification considers economic units as producers of an output *y* which use resources *x*, but acting with some level of inefficiency *u*.

Usually ([6], [7]) the distance is included into spatial models in form of a contiguity matrix *W*, which components w_{ij} contain distances between objects *i* and *j*. Obviously when we speak about interrelation in cross-sectional data, we should exclude the absolute self-dependence from the matrix *W*, so $w_{ii} = 0$. In some cases we need to consider the influence of neighbour objects only (for example, of airports located within 300 km). For these purposes the contiguity matrix can be limited with a pre-defined distance and all other matrix components are replaced with 0 values.

The spatial interrelation is possible between all components of the stochastic frontier model, including the output *y*. We include the spatial dependence of the output into the specification and the resulting model will be autoregressive.

In the general case spatial data structure can have influence on three model's components:

- the efficiency frontier $f(X,\beta)$;
- the inefficiency term *u* as a distribution parameter;
- dispersion of the inefficiency term *u* (heteroscedasticity).

Finally the general spatial autoregressive stochastic frontier model with Cobb-Douglass functional form of the frontier and truncated normal distribution of the inefficiency component can be specified as

$$\ln(y) = \rho \ln(W_1 y) + \beta \ln(X) + v - u,$$
$$u \sim N^{+}(\lambda W_2 y, W_3 \sigma_u^2),$$
$$v \sim N(0, \sigma_v^2)$$

Contiguity matrixes W_1, W_2, and W_3 show spatial dependences in the efficiency frontier, inefficiencies and inefficiency dispersions respectively. Model specification doesn't force matrixes to be the same, and the spatial structure can be different for all three components. Definition of the matrix W is critically important for the model specification. There are a set of different ways to define it[8] – on the base of geographical distance, travel time, or travel cost.

The main problem we note in the standard model specification is unidirectional dependence on spatial components. The ρ coefficient shows the dependence between the output of a given unit and outputs of its neighbour units, and only one conclusion (positive/negative influence or no influence) is possible.

Tobler's law says that neighbour objects influence on another, but it doesn't mean that the influence is the same (and even has the same direction). It is possible that objects, located just around a unit, influence in one direction, and object located in 1 km influence in another direction.

Let image a shopping centre with a set of shops, some of which are operating on the same market (shops of clothes, for example) and obviously are competitors. But since these shops are located at the same shopping centre, cooperation between them (open or hidden) is also possible. If one of shops run an advertisement campaign and attract new customers to the shopping centre – other competitors capture positive effects from this. So we can speak about the cooperation effects in this situation.

Now let consider a new shopping centre located near to the first one. Customers, who visited the second shopping centre, buy necessary clothes there and rarely visit the first centre. In this case we can observe high level of competition and low level of cooperation.

Finally let consider a town where a lot of shopping centres and many shopping tourists from all over the world visit this town for clothes. In this situation we also can note possible cooperation effects.

The similar situation can be observed with airports. Airports which located near to each other can cooperate efficiently due to some reasons:

1. An airport contributes to overall development of a region – businesses, tourists, and infrastructure. All these factors have positive influence on neighbour airports.
2. An airport creates a culture of airlines usage and forms passengers' habits. If a person got accustomed to use airlines for his business and recreational travels, he has higher chances to use neighbour airports.
3. Airport can use the same infrastructure objects and other resources (R&D, for example)

But starting from some distance cooperation effects become weaker, but completion effects can surpass them. For example, development of airports in the neighbour region can lead to moving resources to this region; it's strengthening, and, therefore, enlarging of a competition pressure level. We can speak about competition between regions in this case and airports will be under the competition pressure in this case without any positive cooperation effects.

So influence of neighbour enterprises can differ depending on the distance to them. Mathematically speaking, we have a non-linear influence, and if we will try to approximate this influence with a line – we can receive insignificant or even wrong results. We suggest a modification for spatial models to prevent these problems. Instead of using one contiguity matrix which covers all the area around the point, we can construct a set of matrixes, each cover a ring around the point. For example, the first ring (first tier) includes all objects within 2 km around the point, the second – from 2 to 4 km around, and so on (see Figure 1).

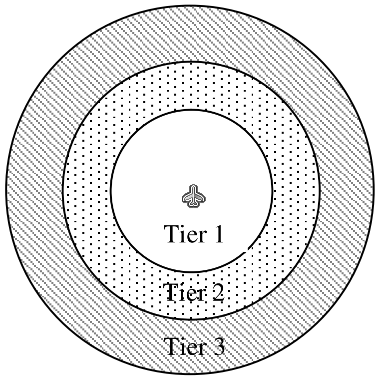

Figure 1. Airport's tiers of spatial dependence

The specification of the suggested spatial multi-tier autoregressive model is (discrete case):

$$y = \sum_{tier=1}^{k} \rho_{tier} W_{tier} y + \beta X + \varepsilon$$

where

- W_{tier} are contiguity matrixes, which contain real distances to objects within the tier and 0 for all object outside the tier;

- ρ_{tier} are coefficients, which show the influence of the neighbours of this tier.

A respective spatial specification of the stochastic frontier model:

$$\ln(y) = \sum_{tier=1}^{k} \rho_{tier} \ln(W_{tier} y) + \beta \ln(X) + \nu - u,$$

$$u \sim N^{+}(\mu, W\sigma_u^2), v \sim N(0, \sigma_v^2)$$

Data

In this research authors use the same dataset as in the previous study [2], new spatial components are calculated on the base of existing data. The data set includes characteristics of European airports' activities from 2003 to 2007.

There are three main data sources used:

1. The Eurostat (the Statistical Office of the European Communities) database is a source of information about airport activities. The information about each airport includes a number of passengers carried (excluding direct transit passengers), a number of direct flights by destination country, a number of employees of airports

(directly hired), and airports' infrastructure (check-in facilities, gates, runways, and parking spaces)

2. The Atlas of Airports from the Ruimtelijk Planbureau, Netherlands, to supplement the Eurostat database.
3. Digital Aeronautical Flight Information File (DAFIF) database and Google Earth as sources of European airports geographical coordinates.

The detailed information about parameters used is presented in [2].

Empirical Results

Following [] we consider an airport as an economic unit which uses its resources to carry passengers (*PassengersCarried*). Airport's resources include runways (*RunwaysNumber*), parking spaces (*ParkingSpaces*) and employees (Employees). In this research this basic set of resources was supplemented with spatial components.

The first empirical problem for spatial model specification is a principle of contiguity matrix selection. We investigated some approaches to matrix construction (distance, travel time, and cost based) and chose the simplest (from the calculation point of view) approach – distance based. We assume that this way can be appropriate, because there are no direct trips between airports in usual situation. Two airports can be considered as neighbour if they service the same area (there catchment areas are intercepted). In this approach there is no significant difference in distance between airports if they have a high-speed/low-cost road/railways between themselves or not. A distance between two points on a sphere (the Earth) correctly calculated using the great-circle distance formula.

At the first stage of the research we formulated the general model and calculated a set of contiguity matrixes for circle with different radiuses around the airport. 10 standard spatial models were constructed starting from a model with 220 km radius of spatial dependence (Model SPAT2) to a model with 1210 km radius (Model SPAT11), with step in 110 km (1 in Euclidean distance ≈ 110 km in great-circle distance). Estimation results for Model SPAT4 (440 km) and Model SPAT 10 (1100 km) are presented in the Table 1.

Table 1. Model SPAT4 (440 km) and Model SPAT 10 (1100 km) estimation results

	Model SPAT4			**Model SPAT10**		
	Coefficient	*z*	*p-value*	*Coefficient*	*z*	*p-value*
Dependent variable Ln(PassengersCarried)						
Frontier						
Ln(ParkingSpaces)	0.095	3.850	0.000	0.102	3.490	0.000
Ln(RunwaysNumber)	1.205	12.910	0.000	1.152	12.120	0.000
Ln(Employees)	0.299	7.670	0.000	0.353	8.030	0.000
Ln(W· PassengersCarried), ρ	0.030	2.640	0.008	-0.155	-2.010	0.045
Constant	12.119	39.070	0.000	15.587	10.620	0.000
Inefficiency						
Ln(W· PassengersCarried), λ	0.308	0.560	0.577	-0.205	-1.770	0.077
Constant	-7.996	-0.520	0.606	4.518	2.120	0.034
Statistics						
γ	0.833			0.681		
Log likelihood	–252.135			–253.337		

General conclusions were the same for all 10 models:

1. All basic resources (runways, parking spaces, and employees) have positive significant coefficient estimates, which match our expectations
2. Stochastic frontier models are significantly better than simple OLS estimate (γ-statistic values are close to 1) and a significant level of inefficiency present in data
3. Influence of the spatial components is not stable over the models; frontier and inefficiency coefficients change significance and even a direction.

We don't pay significant attention to overall model analysis in this paper and concentrate on the analysis of spatial components. Estimates of frontier (ρ) and inefficiency (λ) coefficients for all 10 models are presented in the Table 2 and on the Figure 2.

Table 2. Estimates of frontier and inefficiency coefficients for 10 standard spatial models

Model		**Frontier component, *ρ***			**Inefficiency component, *λ***		
	Approx. distance, km	*ρ*	*z*	*p-value*	*λ*	*z*	*p-value*
SPAT2	220	0.008	1.15	0.249	0.195	0.53	0.597
SPAT3	330	0.042	1.68	0.093	0.066	2.3	0.021
SPAT4	440	0.030	2.64	0.008	0.308	0.56	0.577
SPAT5	550	0.044	3.13	0.002	0.719	0.77	0.443
SPAT6	660	0.052	2.12	0.034	1.258	0.38	0.702
SPAT7	770	0.045	1.04	0.298	0.883	0.53	0.596
SPAT8	880	-0.125	-1.55	0.121	-0.203	-1.78	0.075
SPAT9	990	-0.138	-1.78	0.075	-0.194	-1.73	0.084
SPAT10	1100	-0.155	-2.01	0.045	-0.205	-1.77	0.077
SPAT11	1210	-0.164	-2.11	0.035	-0.212	-1.85	0.065

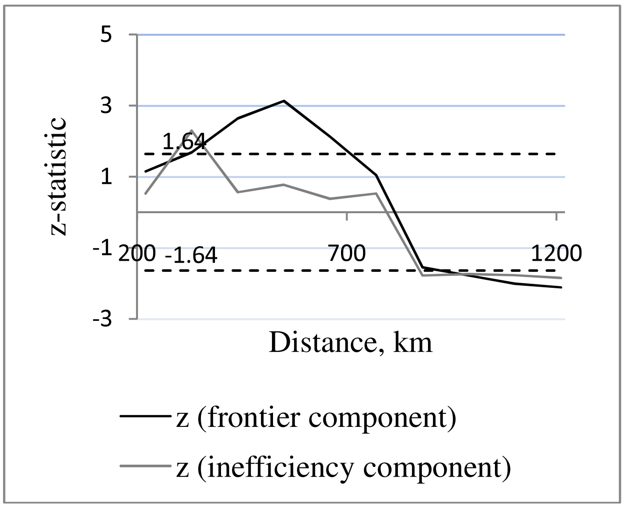

Figure 2. Dependence between frontier and inefficiency coefficients and a radius of spatial dependence

Positive values of the frontier coefficient *ρ* indicate that passengers carried by neighbour airports increase the “production” of a given airport, so this can be considered as a resource. This influence can be interpreted as cooperation effect and we can see that these effects are significant for Models SPAT4, SPAT5, and SPAT6 (440-660km radius).

Negative values of the frontier coefficient *ρ* indicate that successful operations of neighbour airports decrease the production of a given one. This can be explained as competition effects and it is noted for model SPAT10 and SPAT11 (1100+ km radius).

Estimated values of both coefficients take on as significant positive as significant negative values, which support our hypothesis about non-stable influence of neighbour airports on a given one.

Behaviour of the inefficiency coefficient λ looks similar to the frontier one. For models with cooperation effects on the frontier we note positive (significant or near) influence of the spatial component on the inefficiency (increasing), and for models with competition effects – negative influence (decreasing inefficiency). So competition leads to more efficient operations of airports, which agrees with economic theory.

Note that the spatial components of estimated models are nested, because greater circles of spatial dependence contain smaller ones. For example, influence of the spatial component in Model SPAT6 (660 km) includes the influence of the Model SPAT5 (550 km) spatial component and adds influence of airports located in the ring 550-660 km around an airport. This cumulative effect is not very convenient for analysis. For example, the positive significant value of ρ for Model SPAT6 indicates cooperation effects, but as we can see on the chart this influence supplied by airports within 550 km, and the 550-660 km tier only reduces this influence.

To avoid this inconvenience and separate influence of each tier we modified the standard spatial model and instead of one circle spatial component we included a set of spatial tiers (rings) around an airport. We noted on the chart that cooperation effects are increasing up to 550 km distance (Model SPAT5), decreasing after that until 880 km (Model SPAT8), and stabilising after this distance. So we chose three tiers:

1. 220-550 km
2. 550-880 km
3. 880+ km

Respective tier spatial matrixes were calculated and included into the spatial multi-tier autoregressive stochastic frontier model specification. Models estimation results are presented in the Table 3.

Table 3. Spatial multi-tier autoregressive stochastic frontier model estimation results

	Coefficient	*z*	*p-value*
Dependent variable Ln(PassengersCarried)			
Frontier			
Ln(ParkingSpaces)	0.103	4.04	0.000
Ln(RunwaysNumber)	1.255	13.93	0.000
Ln(Employees)	0.350	9.45	0.000
Ln($W_{2\text{-}5}\cdot$ PassengersCarried), ρ_1	**0.032**	2.75	**0.006**
Ln($W_{5\text{-}8}\cdot$ PassengersCarried), ρ_2	**-0.057**	-4.83	**0.000**
Ln($W_{8+}\cdot$ PassengersCarried), ρ_3	**0.010**	1.21	**0.227**
Constant	12.386	36.20	0.000
Statistics			
γ	0.936		
Log likelihood	-239.733		

Most interesting (in terms of model's specification) values are marked in the table with bold.

Estimated influence of the number of passenger carried by neighbour airports is significantly positive within 220-550 km distance. We can make a conclusion about significant cooperation effects between airports located in one region.

Influence of airports located in the 550-880 km tier is significantly negative, so competition effects for these airports are significantly higher than cooperation effects.

Finally, there is no significant dependence from airports operating at 880 km and further from an airport, so cooperation and competition effects are absent or compensate each other.

Possible pattern of cooperation-competition effect power is presented in the Figure 3.

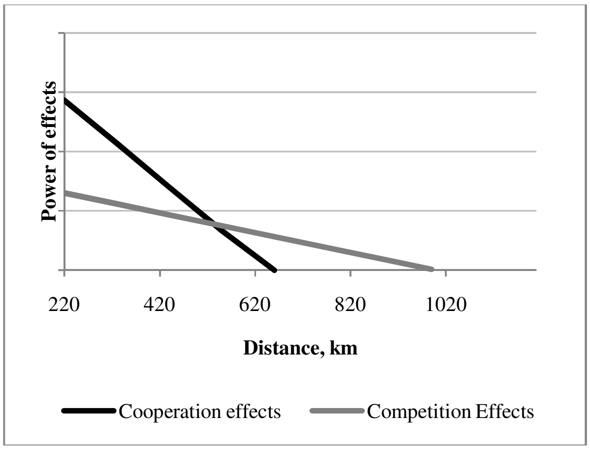

Figure 3. Possible pattern of competition-cooperation effects

According to the sketch cooperation effects are stronger just around an airport, but diminish much faster than effects of competition. This pattern exactly matches the observable behaviour – significant cooperation influence inside the first tier, competition influence in the second one and no significant effects for longer distances.

This analysis can be very important as for airports management as for airport association and government bodies.

Conclusions

In this paper we suggest the new modification of spatial models called spatial multi-tier stochastic frontier models. The feature of these models is an embedded possibility to estimate changing of spatial component influence depending on the distance from a given economic units. This type of models can be useful in situations when influence of neighbour units is not unidirectional, but can vary, and this variation is related with the distance between units. We suggest including spatial components into the model for different distance borders (tiers) separately to analysis the difference of the relationship.

The proposed spatial model modification has a various area of applications. Competition vs. cooperation between economic units, positive vs. negative effects of new buildings/enterprises in a city, differently directed influence in social sciences and other applications presuppose different power and direction of influence. In cases where these differences are spatial and can be explained by the distance between units, the new model specification seems to be useful. One of possible directions of further researches is development of a spatial model without discrete tiers, but with non-linear (possibly functional) dependency from spatial components.

In this research we applied the suggested model to analysis of European airports and their efficiency levels. We used the data from 2003 to 2007 year and received airport's efficiency level estimates. A conclusion about a significant level of inefficiency in airports' operation was done.

Our assumption about varying influence of neighbour airports was confirmed. Cooperation effects overweight competition effects for airports located inside the circle with 550 km. In the next tier, 550-880 km, completion effects become stronger and cooperation are weaker, and so the aggregate influence is add up to competition. Finally, for the third tier, 880 km and more, no competition or cooperation effects are noted.

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