Aerotropolis: an aviation-linked space*

Ricardo Flores-Fillol†- Rosella Nicolini‡

June 16, 2006

Abstract

This paper examines the conditions allowing for the formation of *aeropolitan areas* as large industrial areas with a high concentration of commercial activities in the proximity of cargo airports. When firms deliver part of their production by plane, land competition takes place among service operators, firms and farmers. Service operators supply facilities that firms can take advantage of. Our framework allows selecting a stable land equilibrium: the spatial sequence Airport-Industrial Park-Rural Area (**A**-**I**-**R**). Aerotropolis-type configurations arise around cargo airports when there is an intense use of the airport by the firms and a sufficiently high level of facilities.

Keywords: Aerotropolis; facilities; bid-rent function
JEL Classification: L29; L90; R14

*We are grateful to Jan K. Brueckner, Nicolas Boccard, Xavier Martínez-Giralt and Inés Macho-Stadler as well as the participants at the 4th International Industrial Organization Conference and IAE seminar for their comments and suggestions. R. Flores-Fillol acknowledges financial support from the Spanish Ministry of Education and Science (SEC2002-02506 and BEC2003-01132) and the Generalitat de Catalunya (2005SGR00836). R. Nicolini acknowledges the financial support provided by a *Ramón y Cajal* contract, Barcelona Economics Program CREA, research grants 2005SGR00470 and SEJ2005-01427/ECON.

†Departament d'Economia i d'Història Econòmica, Edifici B, Universitat Autònoma de Barcelona, 08193 Bellaterra (Barcelona), Spain. Tel.: +34935811811; fax: +34935812012; email: rflores@idea.uab.es.

‡Instituto de Análisis Económico (IAE) - CSIC and CREA, Barcelona Economics. Address: IAE, Campus de la UAB, 08193 Bellaterra (Barcelona), Spain. Tel.: +34935806612; fax: +34935801452; email: rosella.nicolini@uab.es.

1 Introduction

Logistics become an increasing important issue because firms need to be even more flexible. Speed and agility are already as important as price and quality for firms that adopt just-in-time strategies. Firms choose their location to enhance their accessibility to markets. Logistics are not longer seen as costs to be minimized, but as value-added activities that need to be optimized. Quoting Mr. Lueck (AMB vice president and asset manager):

> "You can have the best product, the best R&D and the best marketing, but if you can't get your product to the user through the supply chain efficiently, you will lose... Logistics are a value link in the supply chain, providing more than a way to move a box from here to there".

Fast delivery is a key element (see Leinbach and Bowen, 2004 for empirical evidence). Airports are seen (especially by *e-tailers*) as a new kind of Central Business District (CBD) with enough capacity to leverage air commerce into high profits. In that spirit, Kasarda (2000) introduced for the first time the idea of *aerotropolis* (airport city), namely a large industrial area characterized by a high concentration of commercial activities in the area surrounding certain cargo airports. Arend *et al.* (2004) assess that aerotropoli may extend up to 32 kilometers (20 miles), including a number of activities and infrastructures such as retail and distribution centers, light industrial parks, office and research parks, districts zoned for specific purposes, foreign trade zones, entertainment and conference facilities and even residential developments that contribute substantially to the competitiveness of firms belonging to this area.

This paper analyzes the conditions allowing for the formation of *aeropolitan areas* by studying the distribution of commercial activities around an airport. In order to achieve this goal, we ascertain the land sharing process among different agents in the surroundings of an airport that can be either passenger or cargo.

Glaeser and Kahn (2004) suggest studying these phenomena by comparing the different degrees of land-plot occupation by using a concentration measure as density. Their original setting focuses on the analysis of urban sprawl, and refers to the spreading of employment and population in a metropolitan area as well as its concentration in living and working areas. Land equilibrium is driven by the value each type of agent pegs to a land plot at each possible distance from the center. Starting from the model for the location of divisible activities developed by Von-Thünen (1826), various models have tried to explain the configuration of cities where households commute to the CBD and form urban agglomerations around it.[1] As pointed out by Fujita and Thisse (2002), the novelty of Von-Thünen is to

[1] See Fujita and Thisse (2002) for a complete overview of the evolution of this literature in the economics of agglomeration.

introduce the notion of *bid-rent function:* land is not homogeneous and is assigned to the highest bidder. A piece of land at a particular location can be associated with a commodity whose price is not fixed by the market supply and demand. According to Alonso (1964), who adopted the Von-Thünen agricultural model to an urban context, the rent each agent can bid at each location is explained by the savings in transport costs with respect to a more distant site. Hence, land gives rise to a spatial heterogeneity and agents stop bidding for the most distant land since no further savings can be enjoyed.[2] Fujita and Thisse (2002) prove that the spatial heterogeneity generated by an exogenous center (the CBD) allows escape from the Spatial Impossibility Theorem.[3]

This study grants most of its features to urban theory. In that spirit, we consider how commercial firms, *service operators* and farmers compete for land. By service operators we are referring to all firms developing activities associated to the use of the airport. Service operators provide *aviation* and *non-aviation services* to commercial firms. Aviation services account for air transportation activities whereas non-aviation services include a number of complementary services (e.g. freighter docks, bonded warehouse, mechanical handling, refrigerated storage, fresh meat inspection, mortuary, animal quarantine, livestock handling, health officials, security for valuables, decompression chamber, express/courier center, equipment for dangerous and radioactive goods, large or heavy cargo etc.).[4]

Although we adopt the basic features of general urban models, we extend the analysis to consider the easiness with which firms have access to certain *facilities* (for their activity) as a further variable affecting the agent location choice. Our setting is simple. There is a group of service operators supplying a range of services in the proximity of an airport, and firms need to settle close enough to enjoy them. The spatial concentration of these services in the proximity of an airport prevents firms from wasting time in searching for the most suitable ones and reduces their operative costs. Therefore, proximity to the airport allows firms to benefit from an easy access to many facilities (supplied by service operators) also letting them reduce their operating costs. In such a way, firms gain speed in delivering their products and increase the value-added of their activity increase. We model the accessibility to these facilities as an intangible asset that partially reduces firms operative costs and whose exploitation is strongly associated with location (in the spirit of Chipman, 1970).

The idea of introducing an intangible asset (or an externality) as a further force driving agent location choices is not new. There are other studies stressing the importance of ex-

[2] Empirical evidence can be found in Muto (2006).

[3] Spatial Impossibility Theorem: there is no competitive equilibrium involving transportation in a two-region economy with a finite number of consumers and firms; homogeneous space; costly transport; and preferences locally non-satiated (Fujita and Thisse, 2002, pp. 35).

[4] See *www.azworldairports.com* for important non-aviation services provided in the major worldwide airports.

ternalities in determining urban patterns. We recall the study by Brueckner *et al.* (1997) in which the relative location of income groups depend on the spatial distribution of amenities in a city; as well as the contribution by Cavailhès *et al.* (2004) explaining the presence of periurban belts around cities (occupied by both households and farmers) as a consequence of the choice of households to live in the same area as farmers since they value the rural amenities created by farming activities.

Finally, another distinguishing feature in our framework is the presence of transport costs as a quadratic function of the Euclidean distance from each location to an exogenous fixed central business district (CBD). Our idea is to replicate a setting in which the exploitation of the intangible benefits (advantages) is strongly associated with location. With regards to a firm's distance from the CBD, the impact of those benefits becomes small, but the decline of the impact is progressive (and not proportional) with the distance.[5]

The main result of the paper is that aeropolitan areas arise around cargo airports when firms use air commerce services intensively and the level of facilities generated by service operators is sufficiently high. In addition, the model predicts smaller cargo airports relative to passenger airports.

This paper is structured as follows. Section 2 presents some empirical evidence motivating the analysis. Section 3 presents the model, introduces the equilibrium analysis and isolates the required conditions for aeropolitan areas to arise. Section 4 provides some case studies supporting the theoretical results and, finally, Section 5 concludes.

2 Empirical Evidence

In this section, we provide some empirical evidence for the importance of air transport in order to support certain assumptions regarding the framework we develop.[6]

The International Civil Aviation Organization (ICAO) estimates that about 4.5% of the world GDP may be attributed to air transport and its effects upon industries providing either aviation-specific inputs or consumer products. In simple terms, every US $100 of output produced and every 100 jobs created by air transport trigger additional demand of US $325 and in turn 610 jobs in other industries. The total economic contribution of air transport can be measured by looking at the *employment* and *income effects* derived from its *direct* economic activities on the one hand, and from its *indirect and induced* activities

[5] In this respect, empirical evidence can be found in Henderson (2003) or Glaeser and Kahn (2004).

[6] We would like to thank M. Serret (IMADE, Spain), The Alava Development Agency (Spain), E. Maniecki (Chamber of Industry and Commerce of Cologne, Germany), The Frankfurt RhineMain Economic Promotion Board Region (Germany), M.V. Cicogna (ENAC, Italy), W. Küstner (Wirtschaftsfoerderung Region Stuttgart GmbH, Germany) for data and information provided.

(better known as the *multiplier effect*) on the other hand. As one can expect, most of these employment and income effects take place at a regional level, and they are higher than at a national one. They also vary substantially from airport to airport depending on the relationship between the firms and service operators.[7]

The concept of aerotropolis (a large industrial area characterized by a high concentration of commercial activities in the surroundings of some cargo airports) derives from a refinement of the study of the economic effects induced by an airport in its surroundings. It is relatively new. Some aerotropolis projects already exist and others are under construction. Arend *et al.* (2004) mention several examples of aerotropolis. Amsterdam-Shiphol (AMS) is one of the best examples of *mature aerotropolis* since it is surrounded by logistic and office parks; merchandise marts; hotels and entertainment complexes; and there is rail service to Amsterdam, other important cities in Western Europe and major logistic centers. The cases of Memphis (MEM) and Louisville (SDF) in United States; and the cases of Köln-Bonn (CLG) and Vitoria-Foronda (VIT) in Europe (Germany and Spain, respectively) are also the center of well-established aeropolitan areas. Conversely, Dallas-Ft. Worth (DFW) is one of the clearest examples of *aerotropolis under construction*. Particularly, to the east of the airport, the "Las Colinas" area is expanding to accommodate $790,000$ sqm of light industrial space, $121,000$ sqm of retail, $13,000$ family homes, $3,700$ hotel rooms and more than 75 restaurants. Companies such as AT&T, Hewlett-Packard, Exxon, Abbot Laboratories, GTE or Microsoft are already there (Kasarda, 2000). Another example of aerotropolis under construction is the logistically integrated area "PLAZA" in Zaragoza (Spain).[8]

Given the commercial orientation underpinning an aerotropolis*,* it is fairly intuitive to think of aerotropoli developing around cargo airports. In Europe, the specialization between cargo and passenger airports is less pronounced since the major cargo airports are also prominent in passenger activities.

Although any airport can develop both cargo and passenger activities, they are usually classified into two categories (cargo or passenger) by looking at the dominant nature of their operations (see Airports Council International for quantitative statistics). For instance, Memphis (MEM) and Louisville (SDF) are usually classified as cargo airports. They are air-express "mega-hubs" since they are the air base of FedEx and UPS, respectively. Consequently *e-tailers* that normally work in partnership with FedEx and UPS have strong incentives to settle close to these airports.[9]

[7] Referring to ICAO circular (2004) for a few quantitative data.

[8] Data can be obtained at *www.plazadosmil.com*.

[9] For instance, *Barnesandnoble.com*, *Planetrx.com*, *Toysrus.com* or *Williamsonoma.com* are located at MEM; whereas and *Nike.com*, *Drugemporiun.com* or *Gess.com* are located at SDF surroundings.

3 The model

The building blocks of our model are substantially based on Cavailhès *et al.* (2004) and Fujita and Thisse (2002).

Space is represented by the real line $X = (-\infty, \infty)$ with the central business district (CBD) lying at the origin. The CBD is an exogenous fixed point and this corresponds to the airport terminals. We define any spatial distance from it as $x \in X$, with $x > 0$.

There are three types of agents competing for land: *(i)* a continuum of identical service operators of mass N_a and density $n_a(x) \geq 0$ at $x \in X$; *(ii)* a continuum of identical firms of mass N_i and density $n_i(x) \geq 0$ at $x \in X$; and *(iii)* a continuum of farmers of mass N_f density $n_f(x) \geq 0$ at $x \in X$, characterized by bidding a fixed (agricultural) rent $\overline{R}_f$. Land is finite and the total area occupied by service operators, firms and farmers at each $x \in X$ is fixed and normalized to 1 (as in Cavailhès *et al.*, 2004):

$$n_a(x)S_a(x) + n_i(x)S_i(x) + n_f(x)S_f(x) = 1. \tag{1}$$

$S_a(x)$, $S_i(x)$ and $S_a(x)$ stand for the sizes of land plots and $n_a(x)S_a(x)$, $n_i(x)S_i(x)$ and $n_f(x)S_f(x)$ denote the total amount of land being used by each type of agent at a certain location $x \in X$.

Both service operators and firms maximize profits by choosing their optimal land plot at each location $x \in X$. The economy is assumed to be open and agents make zero profits and can freely move. Land is assigned to the highest bidder and therefore land equilibrium is driven by the value each type of agent pegs to a land plot at a each possible distance from the airport center. We define an Airport space (**A**) as a specialized-service operator area (i.e. $n_a(x) > 0$ and $n_i(x) = n_f(x) = 0$); an Industrial Park (**I**) as a specialized-firm area (i.e. $n_i(x) > 0$ and $n_a(x) = n_f(x) = 0$); and finally a Rural Area (**R**) as an area where only farmers live (i.e. $n_f(x) > 0$ and $n_a(x) = n_i(x) = 0$). The relative positions of the areas **A**, **I** and **R** with respect to the CBD are endogenously determined by the bid-rent functions obtained at equilibrium.[10]

Airports can be classified into two categories: cargo and passenger. Since there are some structural features distinguishing the two categories of airports, we present each case separately. A comparison between the equilibrium in the two scenarios allows detecting the conditions that guarantee the existence of an aerotropolis.

[10] A basic approach to the concept of bid-rent function can be found in Zenou (2005).

3.1 The Cargo airport

First, we concentrate on the cargo case by thinking of an airport endowed with a specific infrastructure devoted to cargo activities.

3.1.1 The firm's maximization behavior

A firm located at $x \in X$ produces a quantity of good equal to $q_i(x)$. We assume that firms have to deliver by plane a proportion α of their production, i.e. $q_i^c(x)$ is the quantity of goods delivered through the airport where $q_i^c(x) = \alpha q_i(x)$ and $\alpha \in (0, 1)$. Firms obtain a net price p for each unit of good they sell and have to pay d (airport tariff) for each unit of the production they deliver by plane with $p, d \geq 0$.

Firms benefit from complementary services generated by service operators. In the airport neighborhood, the agglomeration of service operators provides a range of facilities that increase firms' speed and agility in delivering goods thus improving their competitiveness.[11] We model this situation by explicitly introducing the ease of access to facilities as an element reducing the costs that firms incur in delivering through the airport. Its value at $x \in X$ is represented by $A_i(x)$; it is associated with firm location and the land plot of all service operators ($S_A(x)$) at $x \in X$:

$$A_i(x) = \frac{\theta S_A(x)}{tx^2}, \tag{2}$$

where $\theta, t > 0$. Hence, these benefits depend positively (via the parameter θ) on the overall land occupied by service operators settle (i.e. the size of the airport), while they melt with the distance from the airport terminals.[12] In order to capture this feature, transport costs are defined as a quadratic function of the Euclidean distance from the CBD (tx^2).[13] Therefore, $A_i(x)$ is modeled as an intangible asset smoothing the aviation-service cost of firms ($dq_i^c(x)$).

However, as shown by the empirical evidence, firms demand both aviation and non-aviation services (which include a number of complementary services) from service operators.[14] $B_i(x)$ captures the non-aviation expenditures of a firm located at $x \in X$. Finally,

[11] For instance, Leinbach and Bowen (2004) provide a complete study of this phenomenon for the case of Singapore-Changi (SIN).

[12] This expression embodies the simulataneous importance that firms confer to externalities as well as being close to the airport center.

[13] Empirical evidence can be found in Henderson (2003) and Glaeser and Kahn (2004).

[14] Even if non-aviation revenues are not the principal source of earnings for service operators, the report by ICAO (2004) argues that they are progressively increasing. This trend coincides with the present entrepreneurial creativity of service operators in generating non-aviation revenues and improving customer services by providing a wide range of complementary facilities. One can easily realize the importance of non-aviation

firms have to pay a land rent $R_i(x)$. Therefore, the profit function for a firm located at $x \in X$ is:

$$\pi_i(x) = pq_i(x) - R_i(x)S_i(x) - \frac{dq_i^c(x)}{A_i(x)} - B_i(x). \tag{3}$$

Firms' production function takes the form $q_i(x) = S_i(x)^\gamma$,[15] where γ stands for the elasticity of production with respect to firm's plot size and $\gamma \in (0,1)$, i.e. firms have decreasing returns in land size. There is a competition race for land plots between the different group of agents. Firms have an interest in land and we assume that the elasticity of their production with respect to the land is quite high.

Non-aviation expenditures are determined by:

$$B_i(x) = \frac{\beta}{x}(tx^2) = \beta tx, \tag{4}$$

with $\beta > 0$. $B_i(x)$ is composed of two elements: $\frac{\beta}{x}$ represents the *degree of use of non-aviation services* (decreasing with distance), and the transportation costs (tx^2).

By replacing (2) and (4) into (3), we obtain the objective function that firms maximize with respect to $S_i(x)$:

$$\underset{S_i(x)}{Max} \;\; pS_i(x)^\gamma - R_i(x)S_i(x) - \frac{dq_i^c(x)}{\frac{\theta S_A(x)}{tx^2}} - \beta tx$$

The result of the maximization program yields the following optimal land plot for a firm located at $x \in X$:

$$S_i^*(x) = \left(\frac{\gamma(p - \frac{\alpha dtx^2}{\theta S_A(x)})}{R_i(x)} \right)^{\frac{1}{1-\gamma}}. \tag{5}$$

Assumption 1 :

$$p > \frac{\alpha dtx^2}{\theta S_A(x)} \Longrightarrow pq_i(x) > \frac{dq_i^c(x)}{A_i(x)},$$

activities even in liabilities since these activities convey relatively expensive cost of maintenance for the logistical infrastructure (ICAO, 2004 and Passatore, 1998).

[15] This function can be interpreted as a reduced form of a standard Cobb-Douglas function with a second input normalized to one.

i.e. for any firm at $x \in X$, gross profits (namely before using the airport) are greater than aviation costs. Therefore, $S_i^*(x)$ is always positive.

Competition for land among firms implies that they make zero profits. The zero profits condition leads to:

$$R_i^*(x) = \left(\frac{1-\gamma}{\beta t x}\right)^{\frac{1-\gamma}{\gamma}} \gamma \left(p - \frac{\alpha d t x^2}{\theta S_A(x)}\right)^{\frac{1}{\gamma}}, \tag{6}$$

where $R_i^*(x)$ is the bid-rent function for firms, i.e. the highest price a firm is willing to pay for a piece of land at $x \in X$.

By plugging (6) into (5) we obtain:

$$S_i^{**}(x) = \left(\frac{\beta t x}{(1-\gamma)\left(p - \frac{\alpha d t x^2}{\theta S_A(x)}\right)}\right)^{\frac{1}{\gamma}}.$$

Since service operators are identical, the size of the airport can be written as $S_A(x) = N_a S_a(x)$. Hence,

$$S_i^{**}(x) = \left(\frac{\beta t x}{(1-\gamma)\left(p - \frac{\alpha d t x^2}{\theta N_a S_a(x)}\right)}\right)^{\frac{1}{\gamma}} \tag{7}$$

The service operators' optimization problem needs to be solved in order to obtain the values for $S_i^{**}(x)$ and $R_i^*(x)$ and to analyze the land equilibrium.

Each service operator maximizes the following profit function:

$$\pi_a(x) = \frac{(d-c)Q_c(x)}{N_a} + B_a(x) - R_a(x)S_a(x), \tag{8}$$

where d is the airport tariff paid by firms, c the operating unit cost service operators have to bear and $d > c > 0$. Finally, $B_a(x)$ are the non-aviation profits and $R_a(x)$ the land rent for a service operator located at $x \in X$.[16]

[16] As pointed out in ICAO (2004) and Passatore (1998), each airport balance sheet is characterized by this double source of revenues: aviation and non-aviation services. We mention a few examples. According to Passatore (1998), the 1996 revenues of the Stuttgart Airport (STR) can be split into 73% corresponding to aviation and 27% to non-aviation income, while the total income of Frankfurt-Main (FRA) was composed of 66% aviation and 34% non-aviation revenues.

The overall industry production delivered through the airport can be written as $Q_c(x) = N_i q_i^c(x)$ because firms are identical. Since $q_i^c(x) = \alpha S_i(x)^\gamma$ then,

$$Q_c(x) = N_i \alpha S_i(x)^\gamma. \tag{9}$$

The non-aviation profits earned by a service operator take this form:

$$B_a(x) = \frac{\beta}{x} S_a(x), \tag{10}$$

i.e. they depend on the firms' degree of use of non-aviation services ($\frac{\beta}{x}$) and on the size of the service operator supplying the service.

By plugging (7) into (9) and both (9) and (10) into (8) we obtain the objective function that service operators maximize with respect to $S_a(x)$:

$$\underset{S_a(x)}{Max} \;\; \frac{(d-c)N_i \alpha S_i(x)^\gamma}{N_a} + \frac{\beta}{x} S_a(x) - R_a(x) S_a(x),$$

$$s.t. \quad S_i(x) = S_i^{**}(x) = \left(\frac{\beta t x}{(1-\gamma)\left(p - \frac{\alpha d t x^2}{\theta N_a S_a(x)}\right)} \right)^{\frac{1}{\gamma}}.$$

This result yields the following optimal value:

$$S_a^*(x) = \frac{\left(\frac{k(x) \alpha d \theta t x^2}{\frac{\beta}{x} - R_a(x)} \right)^{\frac{1}{2}} + \alpha d t x^2}{p \theta N_a}, \tag{11}$$

where $k(x) = \frac{N_i (d-c) \alpha \beta t x}{(1-\gamma)}$.

Assumption 2

$$\frac{\beta}{x} > R_a(x),$$

i.e. the non-aviation profits obtained by a service operator are higher than the value of the land rent it has to pay at a given location $x \in X$. Therefore, $S_a^*(x)$ is always positive.

As before, the zero profits condition leads to:

$$R_a^e(x) = \frac{\beta}{x}\left(1 - \frac{\theta N_i(d-c)}{d(1-\gamma)}\right), \tag{12}$$

where $R_a^e(x)$ is the equilibrium bid-rent function for service operators, i.e. the highest price a service operator is willing to pay for a piece of land at $x \in X$.

Assumption 3 Let $\frac{\theta N_i(d-c)}{d(1-\gamma)} \leq 1$, then $R_a^e(x) \geq 0$.

By plugging (12) into (11) we obtain the equilibrium land size:

$$S_a^e(x) = \frac{2\alpha d t x^2}{\theta N_a p}. \tag{13}$$

The equilibrium firm size and bid-rent function are obtained by plugging (13) into (6) and (7):

$$R_i^e(x) = \left(\frac{1-\gamma}{\beta t x}\right)^{\frac{1-\gamma}{\gamma}} \gamma \left(\frac{p}{2}\right)^{\frac{1}{\gamma}}, \tag{14}$$

and

$$S_i^e(x) = \left(\frac{2\beta t x}{(1-\gamma)p}\right)^{\frac{1}{\gamma}}. \tag{15}$$

At equilibrium, one can observe that for both firms and service operators land rent decreases in x because land loses its value as agents' distance from the CBD increases. Consequently, land size increases in x since lower rents allow agents to occupy larger plots.

At equilibrium, Assumptions 1 and 2 are always satisfied (see Appendix B).[17] All firms in the industrial area enjoy the same amount of facilities, which can be obtained by plugging (13) into (2):

$$A_i^e = \frac{2\alpha d}{p}.$$

[17] Therefore, the only parameter constraint comes from Assumption 3.

The higher the proportion of production firms deliver by plane (α), the lower the price with respect to the service operators' tariff ($\frac{p}{d}$), and the more firms are able to enjoy facilities.

Finally, since it is assumed that farmers take the residual land, $S_f^e(x)$ is determined by (1):

$S_f^e(x) = \frac{1}{n_f(x)}(1 - n_a(x)S_a^e(x) - n_i(x)S_i^e(x)) = \frac{1}{n_f(x)}(1 - n_a(x)\frac{2\alpha dtx^2}{\theta N_a p} - n_i(x)\left(\frac{2\beta tx}{(1-\gamma)p}\right)^{\frac{1}{\gamma}}),$
and they pay a constant (agricultural) rent ($R_f^e(x) = \overline{R}_f^e$) for this.

3.1.2 Equilibrium analysis

At equilibrium, the highest bidder obtains the use of the land, i.e. $R^e(x) = \max\left\{R_a^e(x), R_i^e(x), \overline{R}_f^e\right\}$.

Proposition 1 *In the neighborhood of a cargo airport, there are two possible (not trivial) land equilibrium configurations: I-A-R (Industrial park-Airport-Rural area), and A-I-R (Airport-Industrial park-Rural area).*

Proof.

1. $\overline{R}_f^e < \min\{R_a^e(x), R_i^e(x)\}$ has to hold at equilibrium because otherwise either the service operators or the firms (or both) get no land.

2. For any $\gamma \in (0,1)$ with $\gamma \neq \frac{1}{2}$, both $R_a^e(x)$ and $R_i^e(x)$ are decreasing and convex and cross only once at $x = x_A \equiv [\frac{\beta}{\gamma}(1 - \frac{\theta(d-c)N_i}{d(1-\gamma)})(\frac{2}{p})^{\frac{1}{\gamma}}(\frac{\beta t}{1-\gamma})^{\frac{1-\gamma}{\gamma}}]^{\frac{\gamma}{2\gamma-1}}$ (see Appendix A for the proof of the single-crossing condition).

   (a) If $\gamma < \frac{1}{2}$, then $R_a^e(x) < R_i^e(x)$ for $\forall\ x < x_A$ and the land equilibrium turns out to be **I-A-R**.

   (b) If $\gamma > \frac{1}{2}$, then $R_a^e(x) > R_i^e(x)$ for $\forall\ x < x_A$ and the correspondent land equilibrium is **A-I-R**.

■

The size of firm land plot affects the total quantity of good supplied by the firms themselves. Therefore, it is reasonable to assume a relatively high elasticity of firms' production with respect to plot size. Under this assumption and according to Proposition 1, the following Corollary holds.

Corollary 1 *Under the realistic assumption of a relatively high elasticity of firms' production with respect to plot size, the land equilibrium is formed by the sequence A-I-R.*

In this case the CBD turns out to be the centre of the airport. An **A**-**I**-**R**-type land equilibrium is presented in Figure 1 below.[18]

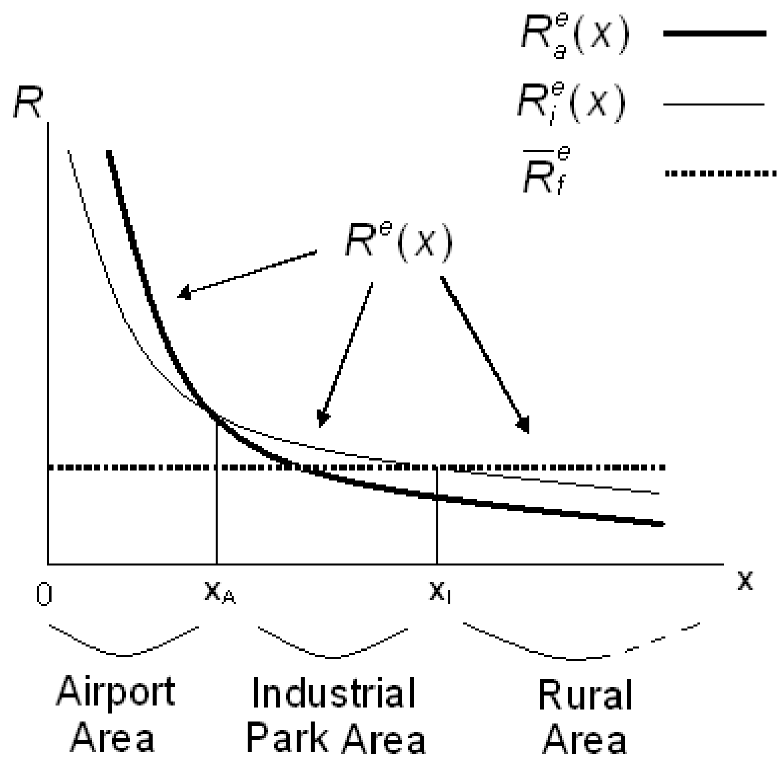

Figure 1: The A-I-R Land Equilibrium

Distance x_A fixes the limit of **A** and x_I bounds the **I** area. At the equilibrium, the land plots are assigned to the highest bidder group (namely, service operators, firms or farmers) and, as a consequence, land appears to be fully specialized. Therefore, $\int_0^{x_A} n_a(x)dx = N_a$ and $\int_{x_A}^{x_I} n_i(x)dx = N_i$. Moreover, since no land is vacant, $n_a(x) = \frac{1}{S_a^e(x)}$ for all $x < x_A$; and $n_i(x) = \frac{1}{S_i^e(x)}$ for all $x \in (x_A, x_I)$.

[18]Figure 3 is drawn by selecting the following paramenters: $\gamma = \frac{2}{3}$, $t = \frac{3}{10}$, $\beta = 2$, $d = 4$, $c = 1$, $N_i = \frac{1}{3}$, $p = 6$, $\theta = 1$.

This result is mainly driven by the maximization behavior of the two groups of agents. On one hand, firms care enough about their land-plot size (i.e. $\gamma > \frac{1}{2}$) because their revenues rely on it; but they also care about service operators' land plot for the facilities they generate. On the other hand, service operators simply care about their own size. In this framework, the **A-I-R** land structure arises because service operators try to settle close enough to the airport so as benefit from larger markets. Firms try to push service operators close to the airport as much as possible in order to rent land space farther from the CBD, since they are not willing to pay expensive rents for the small land plots surrounding the CBD.

Corollary 2 *At an **A-I-R** land equilibrium, the farmer's bid-rent function is bounded from above.*

Proof. The **A-I-R** configuration requires $x_A < x_I$ where $x_I \equiv [(\frac{\gamma}{\overline{R}_f^e})(\frac{p}{2})^{\frac{1}{\gamma}}(\frac{1-\gamma}{\beta t})^{\frac{1-\gamma}{\gamma}}]^{\frac{\gamma}{1-\gamma}}$. This condition leads to $\overline{R}_f^e < \overline{R}_f^{MAX} \equiv [(\frac{\gamma p}{2})^{\frac{\gamma}{3\gamma-2\gamma^2-1}}(\frac{1-\gamma}{\beta t})^{\frac{1}{2\gamma-1}}(\frac{1}{\beta(1-\frac{\theta N_i(d-c)}{d(1-\gamma)})})^{\frac{1}{\gamma}}]^{1-\gamma}$ and therefore, the farmer's bid-rent function cannot be higher than a given threshold. ■

3.2 The Passenger airport

We mostly replicate the analysis performed for the cargo case. For sake of simplicity, we maintain the same notation for parameters, while we add primes to variables to distinguish these from the previous case, but still keeping the same meaning.

3.2.1 The firm's maximization behavior

The aviation services supplied by service operators are mainly addressed to passenger transport and, marginally, to cargo activity. Cargo activity is considered by service operators as a by-product of their passenger operations. Firm's total $(q_i'(x))$ at $x \in X$) production can be split into two parts and only a proportion (α) is delivered by plane. As a consequence, the profit function for a firm located at $x \in X$ turns out to be:

$$\pi_i'(x) = p\left[\alpha q_i'(x) + (1-\alpha)q_i'(x)\right] - R_i'(x)S_i'(x) - \frac{d\alpha q_i'(x)}{A_i'(x)} - B_i'(x), \tag{16}$$

We assume that the share of products delivered by air transport (α) is supplied on a marginal cost basis, i.e. $\alpha q_i'(x)(p - \frac{d}{A_i'(x)}) \to 0$ or equivalently $A_i'(x) \to \frac{d}{p}$ and, hence, (16) reduces to:

$$\pi_i'(x) = (1-\alpha)pq_i'(x) - R_i'(x)S_i'(x) - B_i'(x). \tag{17}$$

Equation (17) shows that firm profits are independent from the airport size $(S_A'(x))$. Hence, firms' maximization program can be computed irrespective of service operators' decisions. (with $q'_i(x) = S'_i(x)^\gamma$) :

$$\underset{S'_i(x)}{Max}\ (1-\alpha)pS'_i(x)^\gamma - R'_i(x)S'_i(x) - B'_i(x).$$

Firms maximization with respect to $S'_i(x)$ yields the following optimal land plot:

$$S'^{*}_i(x) = \left(\frac{(1-\alpha)\gamma p}{R'_i(x)}\right)^{\frac{1}{1-\gamma}}. \tag{18}$$

By applying the zero profits condition, we obtain the equilibrium bid-rent function for firms:

$$R'^{e}_i(x) = \left(\frac{1-\gamma}{\beta t x}\right)^{\frac{1-\gamma}{\gamma}} \gamma[(1-\alpha)p]^{\frac{1}{\gamma}}. \tag{19}$$

Finally, the equilibrium plot size for firms is obtained by plugging (19) into (18):

$$S'^{e}_i(x) = \left(\frac{\beta t x}{(1-\gamma)(1-\alpha)p}\right)^{\frac{1}{\gamma}}. \tag{20}$$

Moving to service operators, each of them maximizes the following profit function:

$$\pi'_a(x) = \frac{(d-c)}{N_a}(T + \mu\frac{Q'(x)}{S'_A(x)}) + B'_a(x) - R'_a(x)S'_a(x), \tag{21}$$

where $\frac{(d-c)}{N_a}(T + \mu\frac{Q'(x)}{S'_A(x)})$ captures aviation profits coming from passenger transportation. Service operators located in the proximity of a passenger airport center specialize in services addressed to passenger traffic. More precisely, T refers to profits issuing from tourist transport, $\mu\frac{Q'(x)}{S'_A(x)}$ refers to the earnings related to business trips with $\mu > 0$, and $(d-c)$ stands for the net benefit per passenger. Profits associated with business trips depend on the *intensity of the airport use* $\frac{Q'(x)}{S'_A(x)}$, which is measured as a trade-off between the dynamism of the region (the more active, the more business trips) and the size of the airport.[19] As in

[19] In that sense, a small airport in a very active region yields a high intensity of airport use and hence high profits related to business trips.

the cargo case, commercial firms and service operators are homogeneous (with mass N_i and N_a, respectively), hence $Q'(x) = N_i q_i'(x) = N_i S_i'(x)^\gamma$ and $S_A'(x) = N_a S_a'(x)$. Since cargo activities are considered by service operators as a by-product of their passenger operations (i.e. a complementary facility), they are included in non-aviation profits ($B_a'(x) = \frac{\beta}{x} S_a'(x)$). The maximization program is:

$$\underset{S_a'(x)}{Max} \ \frac{(d-c)}{N_a}(T + \mu \frac{Q'(x)}{S_A'(x)}) + B_a'(x) - R_a'(x) S_a'(x)$$

$$s.t.\ Q'(x) = N_i S_i'(x)^\gamma,\ S_A'(x) = N_a S_a'(x).$$

Service operator maximization with respect to $S_a'(x)$ yields the following optimal land plot size (and by considering (20):

$$S_a'^*(x) = \left(\frac{(d-c)\mu\beta t x N_i}{(1-\gamma)(1-\alpha)p N_a^2 (\frac{\beta}{x} - R_a'(x))} \right)^{\frac{1}{2}}. \tag{22}$$

Finally, one can obtain the equilibrium bid-rent function and plot size for a service operator:

$$R_a'^e(x) = \frac{\beta}{x} \left[1 - \left(\frac{T}{2\beta} \right)^2 \frac{(d-c)(1-\gamma)(1-\alpha)p}{N_i \mu t} \right], \tag{23}$$

and

$$S_a'^e(x) = \frac{2\mu N_i \beta t x}{N_a T (1-\gamma)(1-\alpha)p}. \tag{24}$$

In the passenger case, Assumption 2 holds as in the cargo case to guarantee a positive land plot for service operators. Conversely, we need to redefine Assumption 3.

Assumption 3′ Let $\left(\frac{T}{2\beta}\right)^2 \frac{(d-c)(1-\gamma)(1-\alpha)p}{N_i \mu t} \leq 1$, then $R_a'^e(x) \geq 0$.

As in the cargo case, land rent decreases in distance (x) and land size increases in x.

At equilibrium, Assumption 2 is fulfilled and the only constraint comes from Assumption 3′. Finally, farmers take the residual land:

$S_f'^e(x) = \frac{1}{n_f'(x)}(1 - n_a'(x) S_a'^e(x) - n_i'(x) S_i'^e(x)) =$

$= \frac{1}{n_f(x)} \left(1 - n_a(x) \left(\frac{2\mu N_i \beta t x}{N_a T (1-\gamma)(1-\alpha)p} \right) - n_i'(x) \left(\frac{\beta t x}{(1-\gamma)(1-\alpha)p} \right)^{\frac{1}{\gamma}} \right)$, and they pay for it a constant rent ($R_f'^e(x) = \overline{R}_f'^e$).

3.2.2 Equilibrium analysis

Proposition 2 *In the neighborhood of a passenger airport, there are two stable land equilibria:* ***I-A-R*** *and* ***A-I-R****.*

Proof. See Proof of Proposition 1. Nevertheless, here, $R_a'^e(x)$ and $R_i'^e(x)$ cross at $x = x'_A \equiv [\frac{\beta}{\gamma((1-\alpha)p)^{\frac{1}{\gamma}}}\left(1-\left(\frac{T}{2\beta}\right)^2\frac{(1-\gamma)(1-\alpha)(d-c)p}{N_i\mu t}\right)(\frac{\beta t}{1-\gamma})^{\frac{1-\gamma}{\gamma}}]^{\frac{\gamma}{2\gamma-1}}$ for any $\gamma \in (0,1)$ with $\gamma \neq \frac{1}{2}$ (see Appendix A for proof of the single-crossing condition). ■

Again, Corollary 1 still holds and we may select the **A-I-R** equilibrium as the most suitable.

Both in the cargo and passenger cases, the land equilibrium implies an **A-I-R** configuration. Nevertheless, the two structures are not identical and the distinguishing features of the **A** and **I** regions differ in the two scenarios (due to the different crossing points). A comparison between the equilibrium in the cargo and the passenger settings allows detecting the conditions that guarantee the existence of an aerotropolis.

3.3 The formation of an aerotropolis: the cargo and passenger cases

After computing of the equilibrium conditions, we focus on the determinants of an aerotropolis area:

Definition 1 *By aerotropolis we are referring to a relatively large industrial park in the proximity of an airport, endowed with a relatively high concentration of firms.*

According to this definition, we need to determine which of our two settings (passenger or cargo airport) can fulfill the two previous conditions, making aerotropoli structures possible. To that end, we need to concentrate on the following two criteria:

- Space dimension: $(x_I - x_A) \lesseqgtr (x'_I - x'_A)$.
- Firm density: $n_i(x) \lesseqgtr n'_i(x)$.

Lemma 1 *When $\alpha > \frac{1}{2}$, in case of a cargo airport:*
i) the capacity of firms to enjoy facilities is higher than in the passenger scenario ($A_i^e > A_i^{e\prime}$);
ii) firms are willing to pay a higher land rent ($R_i^e(x) > R_i'^e(x)$) and they obtain a smaller land plot ($S_i^e(x) < S_i'^e(x)$).

Proof.
i) Easy access to facilities enjoyed by firms in the two scenarios are $A_i^e = \frac{2\alpha d}{p}$ and $A_i^{e\prime} = \frac{d}{p}$, respectively. Hence, $A_i^e > A_i^{e\prime}$ holds for $\alpha > \frac{1}{2}$.

ii) $\left(\frac{1-\gamma}{\beta tx}\right)^{\frac{1-\gamma}{\gamma}} \gamma \left(\frac{p}{2}\right)^{\frac{1}{\gamma}} > \left(\frac{1-\gamma}{\beta tx}\right)^{\frac{1-\gamma}{\gamma}} \gamma \left((1-\alpha)p\right)^{\frac{1}{\gamma}}$ holds for $\alpha > \frac{1}{2}$; and $\left(\frac{2\beta tx}{(1-\gamma)p}\right)^{\frac{1}{\gamma}} < \left(\frac{\beta tx}{(1-\gamma)(1-\alpha)p}\right)^{\frac{1}{\gamma}}$ holds for $\alpha > \frac{1}{2}$. ■

The higher the proportion of production delivered by plane (α), the more facilities firms are able to absorb in the cargo scenario and hence, the $A_i^e - A_i^{e\prime}$ difference increases. Therefore, given a threshold for α, the agglomeration of activities around cargo airports implies gains in terms of speed, agility and complementarities that are valued by firms. In this situation, firms are willing to pay a higher price for land plots in the case of a cargo airport since they enjoy more facilities. Consequently, land plots are smaller.

Corollary 3 *If Lemma 1 holds, industrial parks are denser in firms in the case of cargo airports.*

Proof. An industrial park is a specialized firm area where no land is vacant. Density is given by $n_i(x) = \frac{1}{S_i^e(x)}$ and $n_i'(x) = \frac{1}{S_i'^e(x)}$ in the cargo and passenger cases, respectively. Hence $S_i^e(x) < S_i'^e(x)$ implies $n_i(x) > n_i'(x)$. ■

This result insists on the idea of higher agglomeration of activities around cargo airports.

Lemma 2 *Let $\theta > \underline{\theta}$:*
i) service operators are willing to pay a lower land rent ($R_a^e(x) < R_a'^e(x)$), in the cargo airport;
ii) the cargo is smaller than the passenger airport ($x_A < x'_A$),
with $\underline{\theta} \equiv \left(\frac{d(1-\gamma)}{N_i(d-c)[2(1-\alpha)]^{\frac{1}{\gamma}}}\right)\left([2(1-\alpha)]^{\frac{1}{\gamma}} - 1 + \left(\frac{T}{2\beta}\right)^2 \frac{(1-\gamma)(1-\alpha)p(d-c)}{N_i \mu t}\right)$.

Proof.
i) $\frac{\beta}{x}\left(1 - \frac{\theta N_i(d-c)}{d(1-\gamma)}\right) < \frac{\beta}{x}\left(1 - \left(\frac{T}{2\beta}\right)^2 \frac{(1-\gamma)(1-\alpha)p(d-c)}{N_i \mu t}\right)$ holds for $\theta > \underline{\theta_1} \equiv (\frac{T(1-\gamma)}{2N_i\beta})^2 \frac{dp(1-\alpha)}{\mu t}$.
ii) $[\frac{\beta}{\gamma}(1 - \frac{\theta(d-c)N_i}{d(1-\gamma)})(\frac{2}{p})^{\frac{1}{\gamma}}(\frac{\beta t}{1-\gamma})^{\frac{1-\gamma}{\gamma}}]^{\frac{\gamma}{2\gamma-1}} < [\frac{\beta}{\gamma((1-\alpha)p)^{\frac{1}{\gamma}}}\left(1 - \left(\frac{T}{2\beta}\right)^2 \frac{(1-\gamma)(1-\alpha)(d-c)p}{N_i \mu t}\right)(\frac{\beta t}{1-\gamma})^{\frac{1-\gamma}{\gamma}}]^{\frac{\gamma}{2\gamma-1}}$ holds for $\theta > \underline{\theta}$ (expression in Lemma 2).
It can be ascertained that the second condition over θ is more stringent (i.e. $\underline{\theta} > \underline{\theta_1}$), once Assumption 3′ is fulfilled. More precisely, $\underline{\theta} > \underline{\theta_1}$ holds for $\left(\frac{T}{2\beta}\right)^2 \frac{(d-c)(1-\gamma)(1-\alpha)p}{N_i \mu t} \leq 1$, which is true because it is exactly the condition imposed by Assumption 3′. Finally, since Assumption 3 fixes an upper bound for θ (i.e. $\theta < \overline{\theta} \equiv \frac{d(1-\gamma)}{(d-c)}$), we need to prove that the interval $\overline{\theta} - \underline{\theta}$ exists. It can be checked that $\underline{\theta} < \overline{\theta}$ holds if $\left(\frac{T}{2\beta}\right)^2 \frac{(d-c)(1-\gamma)(1-\alpha)p}{N_i \mu t} \leq 1$, which is always true because it is exactly the condition imposed by Assumption 3′.
■

Moving from a cargo to a passenger-airport setting, the dynamic of the interaction between the two groups of agents does not change dramatically. The main difference is that, in presence of a passenger-type airport, firms do not care about service operators' land plot. This is the reason driving the result in Lemma 2. When firms enjoy facilities from service operators (i.e. $\theta > \underline{\theta}$) fairly substantially in the case of a cargo airport, one important component of firms' strategy is to let service operators occupy land plots in the proximity of the CBD. In that sense, the competition for the land closest to the airport is less fierce and, hence, the rent bidden by service operators can be relatively lower in the passenger case. In the proximity of a passenger airport, firms do not enjoy many benefits from the service operators. Therefore, they do not care about the size and the position of service operators' land plot, but they still care about the size of their own land plot. They still prefer to be a little farther from the CBD than the service operators. The lack of facilities makes firms less prone to pay high rents for their land plot, and since the bid-rent function decreases with respect to distance from the CBD, firms choose to settle farther away than the service operators. As a consequence, passenger-airport surface (composed by the CBD and the land plot of service operators) is larger than that of cargo-airport surface.

Corollary 4 *If Lemmas 1 and 2 hold, industrial areas are larger in the case of a cargo airport.*

Proof. For a given agricultural rent (i.e. $\overline{R}_f^e = \overline{R}_f^{\prime e}$), we obtain $x_I > x_I'$ because $R_i^e(x) > R_i^{\prime e}(x)$. Since $x_A < x_A'$, then $(x_I - x_A) > (x_I' - x_A')$. ■

Hence, industrial parks are denser and larger around a cargo airport.

Proposition 3 *If Lemmas 1 and 2 hold, an aerotropolis arises surrounding a cargo airport, because industrial parks are larger and denser, namely* $(x_I - x_A) > (x_I' - x_A')$ *and* $n_i(x) > n_i'(x)$.

An aerotropolis is empirically defined as a large and dense industrial area located in the surroundings of certain cargo airports where commercial activities concentrate. Our analysis helps to identify the requirements for the emergence of aeropolitan areas. These conditions are basically two: an intense use of the airport by the firms (a high α); and a sufficiently high level of usage of facilities (a high θ). When these conditions are fulfilled, service operators value passenger airports more whereas firms value cargo airports more. In addition, cargo airports are smaller than passenger airports and industrial areas are larger and denser in firms in the presence of a cargo airport. Therefore, an aerotropolis arises. An aerotropolis-type configuration is shown in Figure 2 below:[20]

[20] Figure 4 has been produced by selecting the following paramenters: $\gamma = \frac{2}{3}$, $t = \frac{3}{10}$, $\beta = 2$, $d = 4$, $c = 1$, $N_i = \frac{1}{3}$, $p = 6$, $\theta = 1$ (as in Figure 3) and $\mu = 2$, $\alpha = \frac{6}{11}$, $T = \frac{3}{4}$.

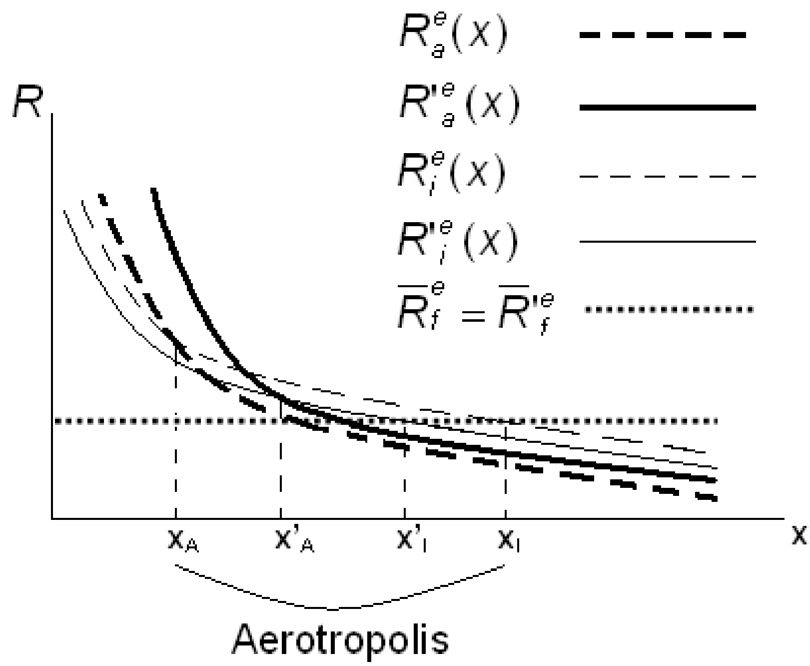

Figure 2: The Aerotropolis

This result is due to the interplay of the forces discussed above. In the cargo case, firms allow service operators enjoy land plots very close to the CBD and the competitive pressure reduces along with the distance from the CBD. At the same time, at equilibrium, the easy access to facilities jointly with a low level of competition makes the average size of the firm's land plot larger between x_I and x_A, and, hence, increases the density of firms (in the surroundings of a cargo) with respect to passenger airports.

4 A sample of case studies

In this section, we present certain case studies in order to provide some empirical support to our theoretical results. Relying on the distinction between cargo and passenger airports, a small sample of European airports is selected for both categories. A comparison between them should give certain insights about the way to distinguish aerotropolis-type configurations from other industrial areas.

The selected airports are: Madrid-Barajas (MAD), Vitoria-Foronda (VIT), and Köln-Bonn (CLG). The first two are Spanish and the third is German. On one hand, MAD is a passenger-type airport. On the other hand, VIT and CLG are the most important cargo-specializing airports in each country.[21]

Although MAD combines passenger and cargo activities, it can be labeled as passenger airport by referring to the predominant nature of its operations. In 2004, MAD recorded traffic of 38.71 million passengers and 0.34 million linear metric tons of delivered goods. In airports such as MAD, *combination carriers* (which transport both passengers and cargo) are the type of companies that mainly operate.

CLG is the second busiest cargo hub in Germany immediately after Frankfurt (FRA), and VIT is the third Spanish cargo airport after MAD and Barcelona (BCN). In 2004, CLG recorded a traffic of 8.4 million passengers and 0.6 million linear metric tons of delivered goods; and VIT recorded a traffic of 0.095 million passengers and 0.04 million linear metric tons of delivered goods. These airports are the base for *integrated carriers* that provide door-to-door express-delivery service. More precisely, FedEx and UPS operate in CLG, whereas FedEx, DHL and TNT operate in VIT.

4.1 A-I-R space configuration

This subsection aims at developing an applied study on the land distribution around airports in order to detect **A-I-R** land configurations.

- **Vitoria-Foronda (VIT).** The airport extends over an area of $150,000$ sqm in the proximity of Vitoria's industrial area. According to the information supplied by the Alava Development Agency,[22] the spatial distribution of activities follows this pattern:

[21] Data from *Airport International* (issue june/july 2005) for CLG; and Annual Report of AENA (2004) for MAD and VIT.

[22] "Álava Agencia de Desarrollo" in Spanish. This agency is under the auspices of the Provincial Government of Alava. Vitoria is the capital of the province of Alava (see *www.alavaagenciadesarrollo.es*).

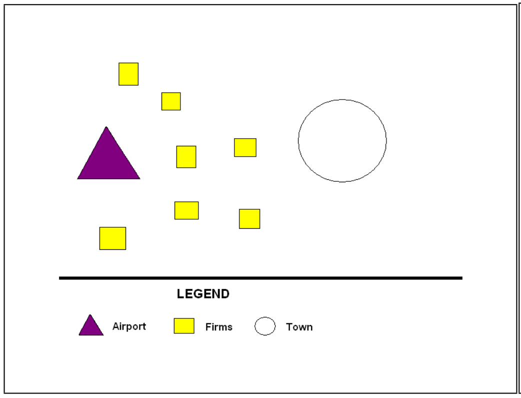

Figure 3: VIT (25 km around)

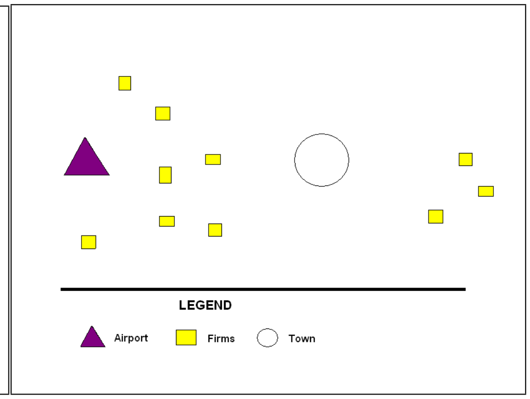

Figure 4: VIT (40 km around)

Taking VIT airport as the reference point (i.e. the CBD) and focusing on the space located within a radius of 25 km, the land distribution seems to adapt to the **A-I-R** scheme [23] and the industrial parks surrounding VIT locate on average 13.12 km from the airport. When we enlarge the radius to 40 km, new industrial agglomerations appear and seem to be located closer to the town than the airport. Therefore, in case of VIT, the **A-I-R** land equilibrium is observed approximately up to a radius of 25 km when considering the airport as CBD. When we consider a greater distance from the CBD, the facilities sourcing from service operators smooth (see Henderson, 2003) and we need to address other arguments in order to explain land configuration.

- **Madrid-Barajas (MAD).** This airport area sizes around $39,000,000$ sqm.[24] The most striking feature of the surroundings of this airport is the high number of industrial parks scattered randomly. This feature makes it difficult to establish a clear-cut space scheme. According to the data supplied by the Madrid Development Institute (IMADE)[25] and the Madrid Chamber of Commerce,[26] the industrial parks surrounding MAD (within a radius of 25 km) locate on average at 14.13 km from the airport. Within this radius, the spatial distribution of activities basically replicates the same pattern as VIT (**A-I-R** spatial sequence). As the distance from the airport increases, externalities decay and the spatial distribution becomes less clear.

[23] No analytical difference is made between urban and rural areas since we are interested in firm (and not household) agglomerations.

[24] This is the total working surface from January 2006. MAD airport recently expanded from $24,000,000$ to $39,000,000$ sqm.

[25] The IMADE ("Instituto Madrileño de Desarrollo" in Spanish) is under the auspices of the Regional Government of Madrid (see *www.imade.es*).

[26] "Cámara de Madrid" (see *http://www.camaramadrid.es/*).

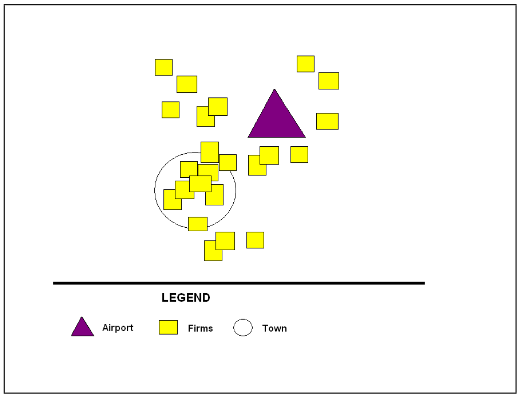

Figure 5: MAD (25 km around)

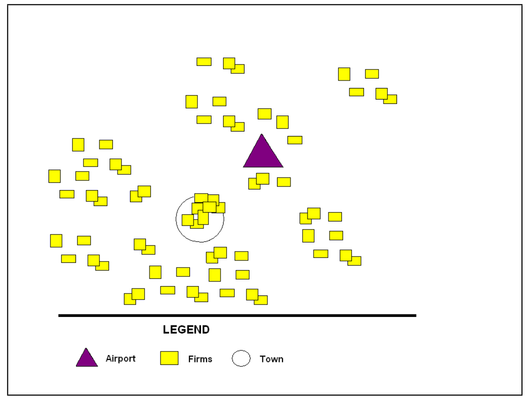

Figure 6: MAD (40 km around)

- **Köln-Bonn (CLG).** This is the second busiest cargo hub in Germany and lies approximately at the same distance from Köln and Bonn (around 15 km). The airport extends over 450, 000 sqm and is characterized by a large number of industrial parks surrounding it. There are around 90 parks including both the existing ones and those under construction within a radius of 40 km, according to the data supplied by the Cologne Chamber of Industry and Commerce.[27]

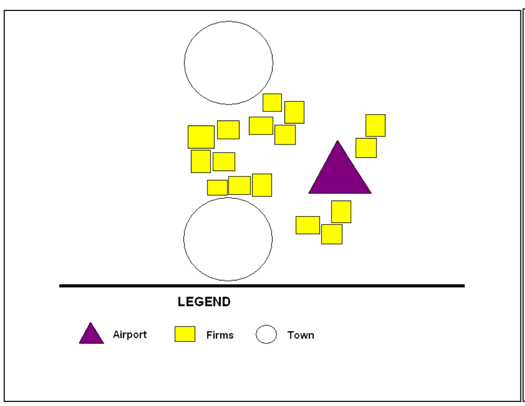

Figure 7: CLG (25 km around)

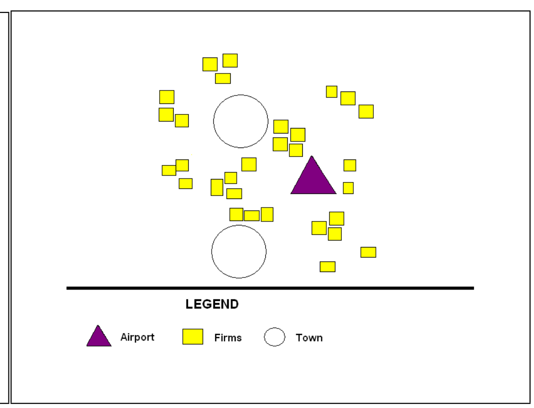

Figure 8: CLG (40 km around)

Within a radius of 25 km, industrial parks are located on average at 15.56 km from the airport, i.e. somewhat further than in the case of VIT and MAD. It is interesting to compare the industrial distribution outlined in Figures 7 and 8. Within the smaller

[27] "Industrie-und Handelshammer zu Köln" (see *www.ihk-koeln.de/index.jsp*).

radius, most of the industrial areas are located between the airport and the cities. However, within the larger radius, the industrial distribution is more scattered and some parks appear beyond the cities. In any event, the **A-I-R** land equilibrium seems to hold in both scenarios.

4.2 Aerotropolis

An aerotropolis requires certain conditions for its development (in terms of α and θ). It has also been shown that cargo airports are smaller than passenger airports (i.e. $x_A < x'_A$) and that industrial areas are larger and denser in firms in the presence of a cargo airport (i.e. $(x_I - x_A) > (x'_I - x'_A)$ and $n_i(x) > n'_i(x)$). Since it is known that the CLG and VIT surroundings feature an aerotropolis-type configuration, it is interesting to ascertain whether the conditions described before are fulfilled.

We divide the analysis into two parts by separately considering the case within 25 km and 40 km from the airport center. The two following tables ($1.A$ and $1.B$) summarize the observed data in order to determine the density of the industrial-park area.[28]

Airport	Airport Extension (sqm) Proxy for S_A	Weighted -Average Distance (km)	Firm Density $(\frac{i}{\sum S_i(x)})\cdot 100$ Proxy for $n_i(x)$
VIT	$150,000$	13.12	0.008
MAD	$39,000,000$	14.13	0.007
CLG	$450,000$	15.56	0.005

Table $1.A$: VIT, MAD, and CLG surroundings (25 km around)

Airport	Airport Extension (sqm) Proxy for S_A	Weighted -Average Distance (km)	Firm Density $(\frac{i}{\sum S_i(x)})\cdot 100$ Proxy for $n_i(x)$
VIT	$150,000$	14.72	0.006
MAD	$39,000,000$	25	0.005
CLG	$450,000$	25.89	0.006

Table $1.B$: VIT, MAD, and CLG surroundings (40 km around)

[28] Data sources: Alava Development Agency (VIT), IMADE and Madrid Chamber of Commerce (MAD) and Cologne Chamber of Industry and Commerce (CLG).

When considering at airport size, the size of cargo airports appears to be the smallest in our sample. Conversely, the study of the weighted distance cannot provide a clear support to the idea that the limit of an aerotropolis (as maximum distance from the airport) is higher than the industrial space close to a passenger airport.[29] The second column in Table 1.A and 1.B does not provide clear information, because the distance does not seem to follow a monotonic path with respect to the category of the airport. It is likely that this feature is strongly related to the size of the airport's basin of attraction that turns out to be strongly associated with the geographical position of the airport in a country or region. Nevertheless, more precise conclusions can be drawn with respect to the density of firms in aerotropolis versus a standard industrial area. We proxy this by the number of firms settled (denoted by i) with respect to the total surface of all industrial parks ($\sum S_i(x)$). Again, a higher density of firms seems to be detected in the cargo cases, confirming the distinguishing features of aerotropolis schemes.[30] In Spain, the VIT and MAD airports fully replicate our theoretical results irrespective of the distance from the airport. The density of firms is always higher in the case of the cargo (VIT) than passenger (MAD) airport and it decreases as far as the distance of the airport increases.

The case of CLG is a bit different. We do not dispose of complete data for a German passenger airport to make the same kind of comparison as for Spain. The magnitude of the density of firms (as in both tables) is comparable to that of Spanish airports, but it does not follow the same decreasing path. Again, this effect may be due to the national or local context in which CLG operates, and more generally to size effects. The regional basin served by CLG may be larger that of Vitoria and, hence, it is possible that the industrial density is somewhat smaller than that of Vitoria. In fact, the weighted-average distance is greater in CLG than in VIT. In addition, when we compare VIT and CLG in the case of the larger distance (40 km), the value of the two densities turns out to be exactly the same.

5 Concluding remarks

The increasing importance of e-commerce leads to airports being considered as a new type of Central Business District (CBD) with sufficient capacity to leverage air commerce into high profits.[31] This paper applies current urban theory for studying the spatial distribution of activities around airports and provides some insights into the formation of aerotropoli. Aerotropoli are defined as large industrial areas characterized by a high concentration of

[29] This is the average of distances for each industrial park with respect to the airport, weighted by the relative number of firms belonging to each park.

[30] More detailed information on the number of parks (corresponding to 2004) can be found in Appendix C. Nevertheless, the index of density is computed by excluding those parks that were either not active or were under construction by the end of 2004.

[31] "...these days the magnets for business are airports...airports are becoming the centres of cities of their own" (The Economist 24/11/2005).

commercial activities in the surroundings of certain cargo airports.

Land competition around airports takes place among service operators, firms and farmers, where firms need to deliver part of their production by plane. In addition to supplying aviation and non-aviation services to firms, service operators generate intangible assets that firms can take advantage of when they are close enough to the airport center. These facilities are the key factor explaining land distribution. As a result of a maximization process, agents associate a value to each unit of land. Finally, location is determined by the comparison of each agent's bid-rent function. In this framework, we select a stable land equilibrium involving service operators, firms and farmers characterized by the Airport-Industrial Park-Rural Area (**A**-**I**-**R**) spatial sequence, irrespective of the category of airport (cargo or passenger).

Aerotropoli develop around cargo airports when firms use airport services quite intensively and the level of facilities is high. Under these circumstances, service operators peg more value to land in the case of a passenger-type airport; whereas firms value land more when the airport is cargo. The size of cargo airports turns out to be smaller than that of passenger airports while industrial areas are larger and denser in the case of a cargo airport. Empirical evidence basically supports these theoretical statements.

A direct implication of this type of analysis concerns policy matters. Once the size of positive effects associated with being close to the airport has been stated, one can think of the economic effects produced by public policies supporting the creation of aerotropoli. The economic contribution of air transport in terms of employment and income has important effects at a regional level. Consequently, regional governments may be interested in trying to implement the required conditions that allow for the formation of aerotropoli. Some policy recommendations would suggest fostering logistical platforms close to cargo airports, promoting and encouraging the partnership between firms and service operators. In such a framework, the intense collaboration among agents would guarantee a sufficiently high level of facilities to allow for the existence of aerotropoli. Of course, this issue would also imply to studying to what extent industrial parks are socially desirable and therefore determining their optimal size. A welfare analysis studying these issues could be an interesting task to undertake in order to extend and apply the main findings presented in this paper.

Another interesting extension of our framework is to adapt it to studying the importance of creating logistic and/or industrial areas in the proximity of transport hubs such as railways stations or harbors. We developed an idea by looking at the specific case of an airport, but the type of results can easily be extended to other transportation infrastructures. From a technical viewpoint, such an application would not involve dramatic changes. Maintaining the suggested structure and changing the parameters of reference and certain interpretations, our conclusions are expected to hold. However, there is a general lack of empirical evidence and statistical data that provides useful support for such an analysis. The scarcity of data and statistics is one of the most binding problems for providing a complete analysis of this phenomenon, even in the case of airports. In fact, most of the analysis that remains to be carried out concerns the empirical analysis of those features distinguishing aerotropolis-type configurations from other industrial areas. Currently, the quality of data and lack of complete time series prevents from dealing with complete econometric estimations that would help in measuring the importance of the factors determining the formation of aeropolitan areas.

References

[1] **Alonso, W. (1964)**, "Location and Land Use", *Harvard University Press.*

[2] **Arend, M., Bruns, A., McCurry, J.W. (2004)**, "The 2004 Global Infrastructure Report", *Site Selection Magazine.*

[3] **AAVV (2005)**, "Business on the Fly", *The Economist,* issue 24.11.2005, electronic edition.

[4] **Brueckner, J.K., Thisse, J.F., Zenou, Y. (1999)**, "Why Central Paris is Rich and Downtown Detroit Poor? An Amenity Based Theory", *European Economic Review*, 43, 91-107.

[5] **Cavailhès, J, Peeters, D., Sekeris, E., Thisse, J.F. (2004)**, "The Periurban City: Why to Live Between the Suburbs and the Countryside", *Regional Science and Urban Economics,* 34, 681-703.

[6] **Chipman, J.S. (1970)**, "External economies of scale and Competitive Equilibria", *Quarterly Journal of Economics*, 87, 347-385.

[7] **Fujita, M., Thisse, J.F. (2002)**, "Economics of Agglomeration. Cities, Industrial Location and Regional Growth", *Cambridge University Press.*

[8] **Glaeser, E.L., Kahn, M.E. (2004)**, "Sprawl and Urban Growth", *Handbook of Regional and Urban Economics* (Henderson, J.V. and Thisse, J.F. Eds), 2482-2527.

[9] **Henderson, J.V. (2003)**, "Marshall's Scale Economies", *Journal of Urban Economics*, 53, 1-28.

[10] **ICAO (2004)**, "Economic Contribution of Civil Aviation" circular 292-AT/124.

[11] **Kasarda, J.D. (2000)**, "Logistics and the Rise of Aerotropolis" *Real Estate Issues*, winter 2000/2001, 43-48.

[12] **Leinbach, Th.R., Bowen, J.T.Jr (2004)**, "Air Cargo Services and the Electronics Industry in Southeast Asia", *Journal of Economic Geography*, 4, 299-321.

[13] **Muto, S. (2006)**, "Estimation of the bid rent function with the usage decision model", *Journal of Urban Economics*, 60, 33-49.

[14] **Passatore, R.(Ed) (1998)**, "Gli Aeroporti Europei: Profili Organizzativi ed Economici", *Instituto Poligrafico e Zecca dello Stato, Roma*.

[15] **Thünen, J.H. von (1826)**, "Der Isolierte Staat in Bezeiehung auf landwirtschaft und Nationalökonomie". *Hamburg: Perthes*. English translation: "The Isolated State". *Oxford: Pergammon Press* (1966).

[16] **Zenou, Y. (2005)**, "Urban Labor Economic Theory. Efficiency Wages, Job Search and Urban Ghettos". Mimeo.

A Appendix: single-crossing condition

The bid-rent function of service operators and that of firms cross at x_A (in the cargo case) and at x'_A (in the passenger case). We prove that x_A and x'_A are the only points equalizing both bid-rent functions (single-crossing condition) by showing that both bid-rent functions are decreasing and convex.

1. **The cargo airport.**

   In the cargo case, the first and second derivatives of service operators and firms' bid-rent functions are (12) and (14):

   (a) $\frac{\partial R_a^e(x)}{\partial x} = -\frac{\beta(1-\frac{\theta(d-c)N_i}{d(1-\gamma)\delta_i})}{x^2}$. This expression is negative for $1 > \frac{\theta(d-c)N_i}{d(1-\gamma)}$, which is always true when Assumption 3 is satisfied. Therefore $R_a^e(x)$ is downward sloping.

   (b) $\frac{\partial^2 R_a^e(x)}{\partial x^2} = \frac{2\beta(1-\frac{\theta(d-c)N_i}{d(1-\gamma)})}{x^3}$. Again by Assumption 3, this expression is positive and therefore $R_a^e(x)$ is convex.

   (c) $\frac{\partial R_i^e(x)}{\partial x} = -\frac{2^{-\frac{1}{\gamma}} p^{\frac{1}{\gamma}} (1-\gamma)^2 (\frac{1-\gamma}{tx\beta})^{\frac{1-2\gamma}{\gamma}}}{tx^2\beta}$, which is negative and hence $R_i^e(x)$ is downward sloping.

   (d) $\frac{\partial^2 R_i^e(x)}{\partial x^2} = \frac{2^{\frac{\gamma-1}{\gamma}} p^{\frac{1}{\gamma}} (1-\gamma)^2 (\frac{1-\gamma}{tx\beta})^{\frac{1-2\gamma}{\gamma}}}{tx^3\beta} + \frac{2^{-\frac{1}{\gamma}} p^{\frac{1}{\gamma}} (1-2\gamma)(1-\gamma)^3 (\frac{1-\gamma}{tx\beta})^{\frac{1-3\gamma}{\gamma}}}{t^2x^4\beta^2\gamma}$. When $\gamma \in (\frac{1}{2}, 1)$, which is a necessary condition for an **A**-**I**-**R**-type land equilibrium to arise, the first term in the expression is positive and the second one is negative. Therefore, the expression will be positive when the first term is higher than the second, i.e. $\frac{2^{\frac{\gamma-1}{\gamma}} p^{\frac{1}{\gamma}} (1-\gamma)^2 (\frac{1-\gamma}{tx\beta})^{\frac{1-2\gamma}{\gamma}}}{tx^3\beta} > \frac{2^{-\frac{1}{\gamma}} p^{\frac{1}{\gamma}} (1-2\gamma)(1-\gamma)^3 (\frac{1-\gamma}{tx\beta})^{\frac{1-3\gamma}{\gamma}}}{t^2x^4\beta^2\gamma}$. This is true for $\gamma > \frac{1}{4}$ which is always the case.

2. **The passenger airport.**

   In the passenger case, the first and second derivatives of service operators and firms' bid-rent functions are (23) and (19):

   (a) $\frac{\partial R_a'^e(x)}{\partial x} = -\frac{\beta(1-\frac{(1-\alpha)(d-c)pT^2(1-\gamma)}{4\beta^2\mu t N_i})}{x^2}$. This expression is negative for $1 > \frac{(1-\alpha)pT^2(1-\gamma)(d-c)}{4\beta^2\mu t N_i}$, which is always true when Assumption 3′ is satisfied. Therefore $R_a'^e(x)$ is downward sloping.

(b) $\frac{\partial^2 R_a'^e(x)}{\partial x^2} = \frac{2\beta(1-\frac{(1-\alpha)(d-c)pT^2(1-\gamma)}{4\beta^2\mu t N_i})}{x^3}$. Again by Assumption 3′, this expression is positive and therefore $R_a'^e(x)$ is convex.

(c) $\frac{\partial R_i'^e(x)}{\partial x} = -\frac{(1-\gamma)^2(\frac{1-\gamma}{tx\beta})^{\frac{1-2\gamma}{\gamma}}[(1-\alpha)p]^{\frac{1}{\gamma}}}{tx^2\beta}$, which is negative and hence $R_i'^e(x)$ is downward sloping.

(d) $\frac{\partial^2 R_i'^e(x)}{\partial x^2} = \frac{(\frac{1-2\gamma}{\gamma})(1-\gamma)^3(\frac{1-\gamma}{tx\beta})^{\frac{1-3\gamma}{\gamma}}[(1-\alpha)p]^{\frac{1}{\gamma}}}{t^2x^4\beta^2} + \frac{2(1-\gamma)^2(\frac{1-\gamma}{tx\beta})^{\frac{1-2\gamma}{\gamma}}[(1-\alpha)p]^{\frac{1}{\gamma}}}{tx^3\beta}$. When $\gamma \in (\frac{1}{2}, 1)$, the first term in the expression is negative and the second term positive. Therefore, the expression will be positive when the first term is lower than the second, i.e. $\frac{(\frac{1-2\gamma}{\gamma})(1-\gamma)^3(\frac{1-\gamma}{tx\beta})^{\frac{1-3\gamma}{\gamma}}[(1-\alpha)p]^{\frac{1}{\gamma}}}{t^2x^4\beta^2} < \frac{2(1-\gamma)^2(\frac{1-\gamma}{tx\beta})^{\frac{1-2\gamma}{\gamma}}[(1-\alpha)p]^{\frac{1}{\gamma}}}{tx^3\beta}$. This is true for $\gamma > \frac{1}{4}$ which is always the case.

B Appendix: Assumptions 1 and 2

In this appendix we provide the proof that Assumption 1 and Assumption 2 are always satisfied at equilibrium.

- **Assumption 1.**

Since $S_A(x) = N_a S_a(x)$, by plugging this value into (13), $S_A(x)$ becomes:

$$S_A^e = \frac{2\alpha dtx^2}{\theta p}. \tag{25}$$

Assumption 1 states that

$$p > \frac{\alpha dtx^2}{\theta S_A(x)}.$$

This inequality, by replacing (25), yields $p > \frac{p}{2}$ which is always satisfied.

- **Assumption 2.**

Assumption 2 states that

$$\frac{\beta}{x} > R_a(x).$$

Finally, this inequality, by replacing (12), yields $\frac{\theta N_i(d-c)}{d(1-\gamma)} > 0$, that is always satisfied because both the numerator and the denominator are positive.

C Appendix: Industrial parks

VIT	Distance from the airport (km)	Extension (sqm)	Number of firms
Technological Park	7	1,117,000	81
CTV	10	500,000	52
Jundiz	12	4,854,220	307
Goain	18	1,613,190	205
Agurain	31	460,564	12
Asparrena San Millan	36	1,317,700	19
Lantaron	40	827,000	12
Okiturri	36	145,322	6

Table 2: Industrial parks 40 km around VIT

MAD	Distance from the airport (km)	Extension (sqm)	Number of firms
Ajalvir	14.5	1,234,142	218
Alcalá de Henares	28.8	14,217,882	303
Camarma de Esteruelas	32.9	1,295,480	60
Coslada	11	3,423,062	332
Daganzo de Arriba	27	855,000	105
Los Santos de la Humosa	29.7	407,400	0
Meco	31.1	3,108,704	50
Paracuellos del Jarama	11	821,560	80
San Fernando de Henares	17	2,847,381	382
Torrejón de Ardoz	17.6	3,538,207	330
Torres de la Alameda	31	1,017,577	2
Villalbilla	28	734,750	0
Madrid Municipio	5.5	23,143,842	320
Morata de Tajuña	36	50,019	0
San Martín de la Vega	39	1,515,000	3
Alcobendas	11.4	4,853,124	770
Algete	21.2	2,013,025	180
Cobeña	19	289,970	1
Colmenar Viejo	39.7	1,035,980	144
Fuente el Saz	15.4	285,514	33
S. Sebastián de los Reyes	19	2,491,735	497
San Agustín de Guadalix	27	1,489,496	15
Torrelaguna	53	282,347	0
Tres Cantos	28	3,108,020	109
Boadilla del Monte	35.5	782,400	24
Las Rozas de Madrid	32.2	2,867,473	254

Table 3: Industrial parks 40 km around MAD pooled by town (PART 1)

MAD	Distance from the airport (km)	Extension (sqm)	Number of firms
Majadahonda	30.5	388,319	0
Pozuelo de Alarcón	30.7	1,154,369	12
Alcorcón	36.7	5,417,676	397
Fuenlabrada	36.8	7,871,224	985
Getafe	27.2	12,468,213	305
Leganés	30.3	7,433,936	331
Moraleja de Enmedio	34	323,779	3
Navalcarnero	54	1,043,361	0
Parla	38.2	7,116,771	1
Pinto	36.5	3,349,207	259
Valdemoro	39.1	5,795,250	38
Arganda del Rey	31.6	5,611,863	771
Campo Real	34	1,193,950	2
Loeches	26	1,210,700	6
Mejorada del Campo	24.3	1,118,000	8
Rivas Vaciamadrid	28	2,670,675	17
Velilla de San Antonio	31	604,400	3

Table 4: Industrial parks 40 km around MAD pooled by town (PART 2)

CLG	Distance from the airport (km)	Extension (sqm)	Number of firms
AirLog	8	530,000	10
Airport Business Park	6	815,000	n.a.
JunkersRing	8	380,000	6
Hotel Europa	8	60,000	n.a.
Chemiepark Knapsack	16	1,600,000	18
City Forum	12	320,000	n.a.
Rheinbach Nord	35	300,000	n.a.
Rheincach Nord II	35	206,755	80
Lindlar Klause	35	557,000	112
Wesseling Süd	25	164,000	7
Bonn West	28	255,000	10
Rösrath Hoffnungsthal	12.7	34,000	1
Alfter Witterschlick	35	82,500	12
Eitorf Alzenbach	35	166,000	24
Bad Honnef Rottbitze	39	160,000	41
Bad Honnef Süd	35	128,300	50

Table 5: Industrial parks 40 km around CLG (PART 1)

CLG	Distance from the airport (km)	Extension (sqm)	Number of firms
Bornheim-Kardorf	31	63,100	n.a.
Pullheim Brauweiler	27.7	590,000	70
Brül Ost	16	100,000	n.a.
Engelskirchen Broich	35	35,900	10
Kerpen-Sindorf	35	271,500	7
Frechen Ost	23	1,180,000	46
Erfstadt Gymnich	38	66,500	21
Kerpen-Sindorf	35	350,000	69
Hennef - Hossenberg	28	230,000	1
Hennef - Stadtzentrum	25	46,000	3
Reinbach Nord	35	400,000	n.a.
Hürth - Hermülheim	16	183,100	9
Köln-Buchheim	13	35,000	n.a.
Köln-Ostheim	7	55,000	n.a.
Köln Porz/Eil	5	62,200	n.a.
Köln-Rath/Heumar	6	115,000	n.a.
Königswinter-Niederdoll.	20	257,200	8
Erfstadt Köttingen NW	33	346,800	15
Kürten-Broich	29	112,000	23
Köln-Merkenich	24	510,000	n.a.
Leichlingen West	35	250,000	n.a.
Lohmar Nordwest	10	180,000	32
NeiderKassel Ost	14	100,000	6
Hürth - Hermülheim Ost	16	1,246,900	100
Oveath Hammermühle	26	98,100	9
Oveath Vilkerath	26	6,500	0
Pulheim Süd Ost	27.4	260,000	0
Pulheim Süd Ost (II)	27.5	85,000	20
Rösrath Brand	12	1,195,000	10
Rösrath Lehmbach	14	50,000	6
Ruppichteroth Nord	35	58,800	7
Ruppichteroth Winter.	33	25,500	3
St Augustin Zentrum	15	104,000	n.a.
St Augustin Buisdorf	15	150,000	n.a.
St Augustin Menden	15	360,000	n.a.
St Augustin Menden Süd	15	307,000	n.a.
St Aug. Zentr. BP113	15	22,000	n.a.
Rösrath Vierkotten	10.3	49,500	0
Siegburg Zange	15	246,900	n.a.
Siegburg Zentrum	15	14,900	n.a.

Table 6: Industrial parks 40 km around CLG (PART 2)

CLG	Distance from the airport (km)	Extension (sqm)	Number of firms
Siegburg Deichhaus	15	157,000	n.a.
Siegburg Stalberg	15	14,500	n.a.
Erftstadt Lechenich	14	568,100	90
Leichlingen Zentrum NW	35	48,000	n.a.
Leverkusen Steinbüchel	20	29,500	9
Troisdorf Zentrum	10	1,277,500	60
Troisdorf West	12	50,000	30
Leichlingen Zentrum W	35	190,000	n.a.
Alfter Nord	30	126,000	3
Wermelskirchen Ostrin.	36	130,000	n.a.
Wesseling Berzdorf	25	172,300	5
Wesseling NW Berzdorf	30	115,000	1
Köln-Ossendorf	20	26,000	n.a.
Brühl Nord	16	192,000	22
Bergisch Gladbach Hand	20	657,000	9
Köningswinter Oberpleis	25	113,500	n.a.
Bornheim Roisdorf J-P	28	164,600	15
Bornheim Hersel Alex.	28	276,250	n.a.
Bornheim-Sechtem	28	36,000	60
Köningswinter Rutt.	25	200,000	13
Alfter Nord	30	517,700	n.a.
Leverkusen Manfort	20	13,320	3

Table 7: Industrial parks 40 km around CLG (PART 3)