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Document de treball nº -28- 2011

DEPARTAMENT D'ECONOMIA – CREIP
Facultat de Ciències Econòmiques i Empresarials

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Edita:

Departament d'Economia
www.fcee.urv.es/departaments/economia/public_html/index.html
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Adreçar comentaris al Departament d'Economia / CREIP

Dipòsit Legal: T -1747- 2011

ISSN 1988 - 0812

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Aerotropolis: an aviation-linked space

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July 2011

Abstract

This paper examines the conditions allowing the formation of *aeropolitan areas* as large industrial areas with a high concentration of commercial activities in the proximity of selected airports. We assume that firms deliver their production by plane and land competition takes place among service operators, firms and farmers. Service operators supply *facilities* that firms can absorb. Our framework identifies a unique land equilibrium characterized by the spatial sequence Airport - Industrial park - Rural area (**A-I-R**). Aerotropolis-type configurations are associated with the level of transport costs and the degree of *intensity of facilities*.

Keywords: aerotropolis; facilities; bid-rent function

JEL Classification Numbers: L29; L90; R14

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1 Introduction

Logistics are becoming an increasingly important issue because firms are in search of flexibility. Speed and agility are already as important as price and quality in the strategy of 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. According to 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".[1]

Fast delivery is a key element (see Leinbach and Bowen, 2004 for empirical evidence). In this context, 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 surroundings of specific airports. Arend *et al.* (2004) suggest that aerotropoli may extend up to thirty-two kilometers (twenty 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 the area.

[1] This quotation appears in Arend *et al.* (2004).

Given the commercial orientation underpinning an aerotropolis, it is reasonable to assume that they will develop around cargo airports. The best examples of aerotropolis are therefore located in the US, where the cases of Memphis (MEM) and Louisville (SDF) are especially relevant.[2] These airports 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.[3]

This paper analyzes the conditions allowing for the formation of *aeropolitan areas* by studying the distribution of 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.

Our approach is to study this phenomenon through a land competition model. In a similar way, Glaeser and Kahn (2004) study urban sprawl by focusing on the spread of employment and population 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), several models have tried to explain the configuration of cities where households commute to the CBD and form urban agglomerations around it.[4] As pointed out by Fujita and Thisse (2002), the novelty of Von-Thünen is the introduction of 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

[2] In Europe, the specialization between cargo and passenger airports is less pronounced than in the US.

[3] For instance, *Barnesandnoble.com*, *Planetrx.com*, *Toysrus.com* and *Williamsonoma.com* are located at MEM; *Nike.com*, *Drugemporiun.com* and *Gess.com* are located at SDF surroundings. In addition, Bel and Fageda (2008) provide an empirical study on the importance of the quality of air services as a determinant for the location of headquarters.

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

whose price is not fixed by the market supply and demand. In the wake of Von-Thünen, according to Alonso (1964), the rent each agent can bid at each location is compensated 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.[5] Fujita and Thisse (2002) prove that the spatial heterogeneity generated by an exogenous center (the CBD) allows escape from the Spatial Impossibility Theorem.[6]

This study owes many of its features to urban theory and, in that spirit, we consider how different agent types compete for land. We thus assume the existence of commercial firms, *service operators* and farmers. We consider firms that provide *aviation* and *non-aviation services* to commercial firms (i.e., airlines in a broader sense) to be service operators. Aviation services account for air transportation activities whereas non-aviation services include a number of complementary services which a commercial firm may require (e.g. freighter docks, bonded warehouses, 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.).[7]

Our fuel for land competition is the easy accessibility to specific *facilities* that operators provide and firms need. Our setting is simple. There is a group of service operators supplying a range of services in the proximity of an airport, and firms consider settling close enough to them to enjoy better the facilities the service operators provide. This type of incentive is modelled as

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

[6] 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).

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

an intangible asset that partially reduces firms' operating costs and whose exploitation is strongly associated with the firm location (in the spirit of Chipman, 1970).

The idea of introducing an intangible asset (or an externality) as a force driving agent location choices is not new. There are other studies stressing the importance of externalities in determining urban patterns. We recall the study by Brueckner *et al.* (1999) in which the relative location of income groups depends 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 decision by households to live in the same area as farmers since they value the rural amenities created by farming activities.

The main outcome of this paper is that there is a unique land equilibrium composed by the sequence Airport - Industrial park - Rural area (**A**-**I**-**R**); and that aerotropolis land configurations are more likely to appear in non-exploited areas where transport costs are high and there is a high *intensity of facilities*. The cases of MEM and SDF comply with the conditions identified by the analysis and grant a strong empirical evidence for our predictions.

The paper is structured as follows. Section 2 presents the model and Section 3 introduces the equilibrium analysis. Some case studies are presented in Section 4 and, finally, Section 5 concludes.

2 The model

The building blocks of our model are based substantially 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 with density $n_a(x) \geq 0$ at $x \in X$; *(ii)* a continuum of identical firms with density $n_i(x) \geq 0$ at $x \in X$; and *(iii)* a continuum of farmers with 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 $S_f(x)$ 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 location $x \in X$.

Both service operators and firms maximize profits by choosing their optimal land plot at each location $x \in X$. 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 each possible distance from the airport center and, consequently, land is specialized after the bidding process. Thus, we define an Airport space (**A**) as a specialized-service operator area (i.e. $n_a^*(x) > 0$ and $n_i^*(x) = n_f^*(x) = 0$) where superscript $*$ denotes the *ex-post* equilibrium density. In the same way, an Industrial park (**I**) is 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.[8]

2.1 The competition mechanism

A commercial firm i located at $x \in X$ produces a quantity of good equal to $q_i(x)$ that needs to be delivered through the airport. A service operator a located at $x \in X$ supplies aviation and non-aviation services to commercial firms. We assume that the *ex-ante* density (i.e., before the bidding process) of commercial firms and service operators is the same at each $x \in X$ (i.e. $n_a(x) = n_i(x), \forall x \in X$).

Firms' production function is dependent on its own land plot. The function takes the form $q_i(x) = S_i(x)^\gamma$,[9] where γ stands for the elasticity of production with respect to firm's plot size and $\gamma \in (0, 1)$, i.e. firms exhibit decreasing returns with respect to land plot. Firms sell their goods at a final price p (net of production costs) per unit and have to pay a per-unit tariff d to service operators to deliver them (for instance as an aviation tariff) with $p > d > 0$. The aviation benefits for commercial firms are therefore $(p - d)S_i(x)^\gamma$. These benefits have to cover the land rent, a part of the transport costs and the purchase of non-aviation services.

Land rent is $R_i(x)S_i(x)$, where $R_i(x)$ is the rental price and $S_i(x)$ the land-plot size at a certain distance $x \in X$ from the CBD. For sake of simplicity, we assume that transport costs are split equally between the two categories of firms. In a standard fashion, for each type of firm (a or i), transport costs are linear and equal to tx with $t > 0$.

Additionally, firms also purchase non-aviation services from service operators at a price $g > 0$. These services are produced by service operators with the following technology $q_a(x) = S_a(x)^\gamma$.

[8] A basic approach to the concept of bid-rent function can be found in Zenou (2009).

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

As regards for commercial firms, service operators exhibit the same elasticity of production with respect to plot size (γ). Thus, the non-aviation costs for commercial firms amount to $gS_a(x)^\gamma$.

Commercial firms evaluate positively the agglomeration of service operators providing non-aviation services in the proximity of the CBD. In fact, their agglomeration generates an easy access to *facilities* that constitute a positive externality for firms improving their competitiveness.[10] We model this situation by explicitly considering that, for a firm i located at $x \in X$, the technology allowing for the exploitation of facilities is $F_i(x) = f\left[n_a(x)S_a(x)\right]^\varepsilon$. It relies positively on the total amount of land occupied by service operators with $\varepsilon \in (0,1)$ and f being interpreted as a measure of the *facility intensity*. A higher service operators' density implies that it is more likely that firms will have access to services, whereas a bigger land plot occupied by service operators embeds the idea of a wider range of services they can provide. The *intensity of facilities* smooths firm's non-aviation costs and we assume that these facilities reduce the non-aviation bill for firms and thus we can rewrite the non-aviation costs net of facilities as $\frac{gS_a(x)^\gamma}{f[n_a(x)S_a(x)]^\varepsilon}$ or equivalently $\frac{kS_a(x)^\beta}{n_a(x)^{\gamma-\beta}}$, where $k = \frac{g}{f}$ and $\beta = \gamma - \varepsilon > 0$.[11]

Finally, in order to have a tractable expression at the equilibrium, we need to introduce an explicit form for the *ex-ante* density function $n_a(x)$. Following Song (1996),[12] we can associate the ex-ante density function with a measure of accessibility, so that a location has a higher accessibility if it is closer to the CBD. A common measure of accessibility adopted in the literature is a decay-distance function. The simplest way to define an accessibility function h between two points (i,j) is to set it equal to the inverse of the linear distance between the points (x_{ij}), i.e., $h(x_{ij}) = x_{ij}^{-1}$.[13]

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

[11] Considering $\gamma > \varepsilon$, we limit the impact of facilities in reducing firms' non-aviation costs.

[12] Song (1996) provides a full compendium of density functions.

[13] In addition, this accessibility measure we are adopting seems to perform very well in the empirical estimations

Then, a density function at a location x (with x measuring the distance from the CBD) is defined as the combination between the accessibility measure and the mass of agents. Assuming that the mass of service operators is N_a (that would ideally settle at the CBD), the density function of service operators located at x takes the following expression: $n_a(x) = N_a x^{-1}$. We can normalize N_a to one such that this density becomes $n_a(x) = x^{-1}$.[14]

From the previous reasoning, the profit function for a commercial firm located at $x \in X$ is

$$\pi_i(x) = \underbrace{(p-d)S_i(x)^\gamma}_{\text{Aviation profits}} - \underbrace{R_i(x)S_i(x)}_{\text{Land rent}} - \underbrace{kx^{\gamma-\beta}S_a(x)^\beta}_{\text{Non-aviation costs}} - \underbrace{tx}_{\text{Transport costs}} . \tag{2}$$

On the other side, the service operators earn aviation and non-aviation revenues from firms, and pay a land rent and transport costs in a similar way as firms. Hence, the profit function for a service operator at $x \in X$ can be expressed as

$$\pi_a(x) = \underbrace{dS_i(x)^\gamma}_{\text{Aviation revenues}} - \underbrace{R_a(x)S_a(x)}_{\text{Land rent}} + \underbrace{kx^{\gamma-\beta}S_a(x)^\beta}_{\text{Non-aviation revenues}} - \underbrace{tx}_{\text{Transport costs}} . \tag{3}$$

By construction, the existence of facilities reduces non-aviation costs for commercial firms but also non-aviation revenues for service operators. The rationale is that facilities represent a kind of *public good* freely accessible to commercial firms. Thus, the more facilities they exploit, the less *expensive* non-aviation services turn out to be.

Also notice that, since we are assuming $\gamma > \varepsilon$ and $\beta = \gamma - \varepsilon$, then $\gamma > \beta$. By interpreting γ and β as the share of aviation and non-aviation revenues respectively, we are suggesting that aviation services are the principal source of revenue in service operators' balance sheet.[15] Although non-

undertaken in Song (1996).

[14] The case of a constant ex-ante density function ($n_a(x) = n_i(x) = 1$) is also presented in Appendix B.

[15] 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

aviation services are not the principal source of earnings for service operators, the report by ICAO (2004) argues that they are progressively increasing.[16]

2.2 The maximization problem

Firms maximize profits $\pi_i(x)$ with respect to plot size, i.e.

$$\underset{S_i(x)}{Max}\ (p-d)S_i(x)^{\gamma} - R_i(x)S_i(x) - kx^{\gamma-\beta}S_a(x)^{\beta} - tx,$$

and the first-order condition for a commercial firm i located at $x \in X$ yields

$$S_i(x) = \left[\frac{\gamma(p-d)}{R_i(x)}\right]^{\frac{1}{1-\gamma}}.$$

The plot size logically increases firms' margin and with the elasticity of production, whereas it decreases with the rental price. Competition for land among firms implies that land rent extracts all firms' profits, and this zero-profit condition leads to

$$R_i(x) = \left[\frac{(1-\gamma)(p-d)^{\frac{1}{1-\gamma}}\gamma^{\frac{\gamma}{1-\gamma}}}{kx^{\gamma-\beta}S_a(x)^{\beta}+tx}\right]^{\frac{1-\gamma}{\gamma}}, \tag{4}$$

where $R_i(x)$ is the bid-rent function for firms, i.e., the highest price a firm is willing to pay for a

(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.

[16] 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 detect the importance of non-aviation activities even in liabilities since these activities incur relatively hight maintenance costs for the logistical infrastructure (ICAO, 2004; and Passatore, 1998).

piece of land at $x \in X$. Then, coming back to $S_i(x)$ we get

$$S_i(x) = \left[\frac{kx^{\gamma-\beta}S_a(x)^\beta + tx}{(1-\gamma)(p-d)}\right]^{\frac{1}{\gamma}}. \tag{5}$$

When we look at the service operators' side, their maximization problem becomes

$$\begin{gathered}\underset{S_a(x)}{Max}(p-d)S_i(x)^\gamma - R_i(x)S_i(x) + kx^{\gamma-\beta}S_a(x)^\beta - tx \\ s.t.\ S_i(x) = \left[\frac{kx^{\gamma-\beta}S_a(x)^\beta+tx}{(1-\gamma)(p-d)}\right]^{\frac{1}{\gamma}},\end{gathered}$$

and the first-order condition of the previous maximization problem yields

$$S_a(x) = \left[\frac{kx^{\gamma-\beta}\beta(1+w)}{R_a(x)}\right]^{\frac{1}{1-\beta}},$$

with $w \equiv \frac{d}{(1-\gamma)(p-d)}$. As before, the plot size typically increases with the (net) elasticity of production with respect to plot size β, whereas it decreases with the rent cost. Moreover, the plot size also increases with the aviation tariff d and with the price of non-aviation services net of facilities k. As for commercial firms, land competition extracts all profits from service operators (zero-profit condition) yielding

$$R_a^*(x) = \beta\left[kx^{\gamma-\beta}(1+w)\right]^{\frac{1}{\beta}}\left[\frac{(1-\beta)}{tx(1-w)}\right]^{\frac{1-\beta}{\beta}}, \tag{6}$$

and coming back to $S_a(x)$ we get

$$S_a^*(x) = \left[\frac{tx^{1-\gamma+\beta}(1-w)}{(1-\beta)k(1+w)}\right]^{\frac{1}{\beta}}, \tag{7}$$

where superscript $*$ denotes the land equilibrium values.

Finally, introducing the expressions (6) and (7) into (4) and (5), we get the firms' equilibrium values

$$R_i^*(x) = \gamma(p-d)\left[\frac{d(1-\beta)(1+w)}{wtx\left[(1-w)+(1-\beta)(1+w)\right]}\right]^{\frac{1-\gamma}{\gamma}} \tag{8}$$

and

$$S_i^*(x) = \left[\frac{wtx\left[(1-w)+(1-\beta)(1+w)\right]}{d(1-\beta)(1+w)}\right]^{\frac{1}{\gamma}}. \tag{9}$$

The sole parametric conditions we need to observe to have positive equilibrium values are $0<\beta<\gamma<1$, i.e. aviation operations are the principal activity carried out by service operators, and $w \in (0,1)$, which is a natural condition that requires firms' aviation margin $(p-d)$ to be sufficiently large.[17] At the equilibrium, one can realize that land rent decreases with x both for firms and service operators because land loses its value as agents' distance from the CBD increases. Consequently, land plot size increases with x since lower rents allow agents to occupy larger plots.

Interestingly, we can rewrite $R_a^*(x)$ and $R_i^*(x)$ as a function of the equilibrium plot size

$$R_a^*(x) = \frac{\beta k x^{\gamma-\beta}(1+w)}{S_a^e(x)^{1-\beta}} \text{ and } R_i^*(x) = \frac{\gamma(p-d)}{S_i^e(x)^{1-\gamma}}, \tag{10}$$

[17] The effect of the parameters in the equilibrium values is analyzed in the comparative-statics exercise presented in the next section.

which confirms the inverse relationship between plot size and land rent also at the land-rent equilibrium.

3 Equilibrium analysis

At the equilibrium, we observe that $R^*(x) = \max\left\{R_a^*(x), R_i^*(x), \overline{R}_f^*\right\}$, i.e. the highest bidder obtains the use of the land, where $\overline{R}_f^*$ stands for the constant (agricultural) rent bid by farmers at any location $x \in X$. As a consequence of the bidding process, land is specialized in equilibrium and no land is vacant.

Remark 1 *At $x \in X$, commercial firms and service operators compete for land if and only if $R_i^*(x) > \overline{R}_f^*$ and $R_a^*(x) > \overline{R}_f^*$.*

In a specialized-service-operator area, i.e., an Airport (**A**), it is easy to see that $n^*(x) = \frac{1}{S_a^*(x)}$ from (1). Equivalently, in a specialized-firm area, i.e., an Industrial park (**I**), we observe $n_i^*(x) = \frac{1}{S_i^*(x)}$; and finally, in a Rural area (**R**) where only farmers live we observe $n_f^*(x) = \frac{1}{S_f^*(x)}$.

3.1 The A-I-R land equilibrium

In this framework, we are able to prove that there is a unique land equilibrium, as summarized in the proposition below. The proof is provided in Appendix A.

Proposition 1 *Bid-rent functions $R_i^*(x)$ and $R_a^*(x)$ only cross once at $x_A > 0$ and there is a unique equilibrium characterized by the land sequence **A**-**I**-**R** for a sufficiently low $\overline{R}_f^*$.*

As a result, we find an **A** area for $x \in (0, x_A)$; an **I** area for $x \in (x_A, x_I)$; and a **R** area for $x > x_I$. The **A**-**I**-**R**-type land equilibrium is presented in Figure 1 below.[18]

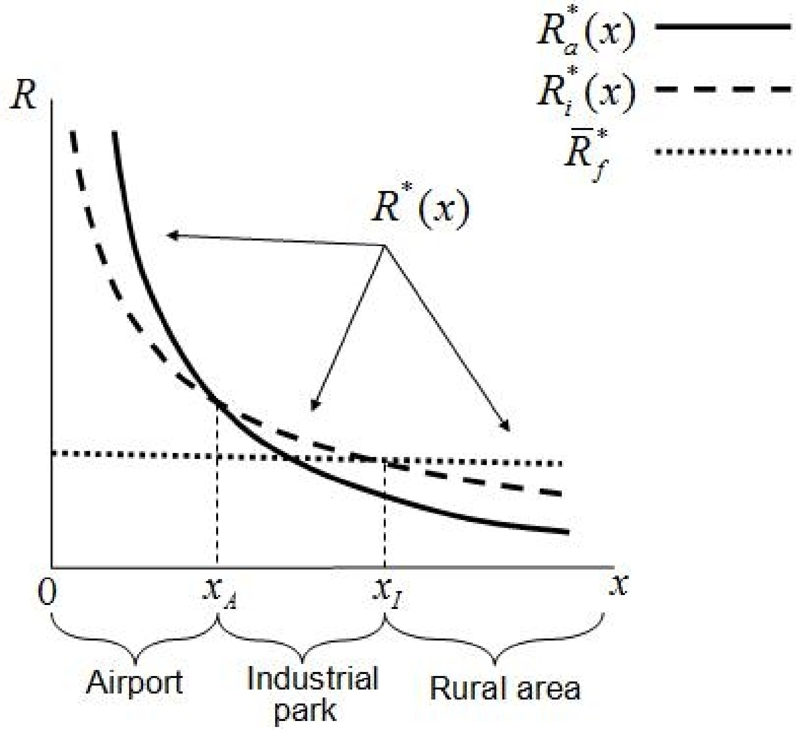

Figure 1: The A-I-R equilibrium

This land configuration in proximity of the airport is driven by the interaction between service operators and firms. Both agent types care about their own plot size but also about the other agent's plot size. In fact, we observe at the equilibrium that firms try to *push* service operators as close as possible to the airport in order to rent land space further from the terminals, since they are not willing to pay expensive rents for the small land plots surrounding the CBD.

[18] Figure 1 is drawn by selection of the following parameter values: $\gamma = 3/4$, $\beta = 1/3$, $p = 6$, $d = 1$, $t = 2$, $g = 2$ and $f = 2$. These values do not, however, determine the equilibrium type.

It is possible to compute the value of x_A that corresponds to the intersection between the bid-rent functions of the two types of firms (i.e. (6) and (8)):

$$x_A = \left(\frac{\beta \left[k(1+w)\right]^{\frac{1}{\beta}} \left[\frac{(1-\beta)}{t(1-w)}\right]^{\frac{1-\beta}{\beta}}}{\gamma(p-d)\left[\frac{d(1-\beta)(1+w)}{wt[(1-w)+(1-\beta)(1+w)]}\right]^{\frac{1-\gamma}{\gamma}}} \right)^{\frac{\gamma\beta}{(1-\gamma)(\gamma-\beta)}}, \qquad (11)$$

and, given the assumptions made on the parameters, x_A is always positive. Having the explicit value of x_A will be useful in the comparative statics analysis presented in the next subsection.

3.2 Comparative statics

In order to illustrate the properties of the **A-I-R** equilibrium, it is useful to provide some comparative statics.

The effects of the variation of parameters d, p, γ and β are difficult to assess because there is both a *direct effect* and an *indirect effect* due to the interaction between both agent types. For instance, consider the case of an increase in the aviation tariff d. The *direct effect* would benefit service operators (because their revenues increase) and harm firms (because their costs increase), as it can be seen in (2) and (3). As a result, service operators' willingness to pay increases ($R_a(x) \uparrow$) and firms' willingness to pay decreases ($R_i(x) \downarrow$).

Nevertheless, there is also an *indirect effect* coming from the interaction between both agent types. Since there is an inverse relationship between willingness to pay and plot size, service operators' plot size tends to decrease ($S_a(x) \downarrow$) and firms' plot size tends to increase ($S_i(x) \uparrow$). This is positive for firms because their aviation profits increase and their non-aviation costs decrease; and the effect for service operators is ambiguous because their non-aviation revenues decrease whereas their aviation revenues increase. Thus, the overall effect is unclear.

We have unambiguous effects, however, for changes in facility intensity (f), non-aviation prices (g) and per-mile transport costs (t). In fact, we can get some insights by simulating and plotting the values of x_A against f and t respectively.[19]

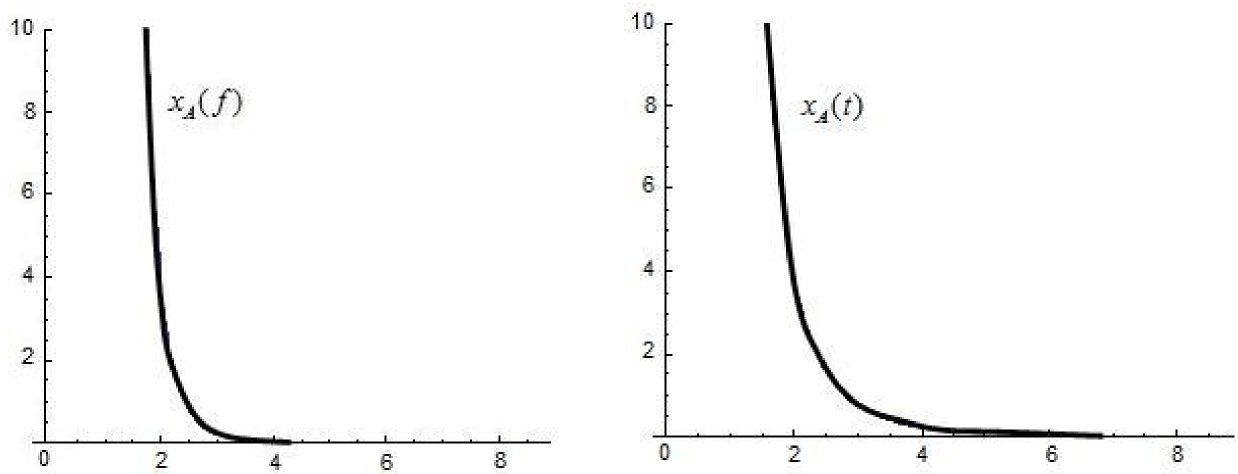

Figure 2: $x_A(f)$ and $x_A(t)$

The degree of competition for land by firms determines the distance of x_A with respect to the CBD ($x = 0$), and therefore the size of the Airport area.

The presence of facilities increases the interest for firms to locate close to the CBD. The competition for land by firms will therefore be softer for lower values of f and, consequently, the Airport area (x_A) will be larger because there will be more space being occupied by service operators. Instead, the presence of a higher facility intensity makes competition for land fiercer, and thus x_A decreases.

[19] These two figures are drawn by selection of the following parameter values: $\gamma = 3/4$, $\beta = 1/3$, $p = 6$, $d = 1$ and $g = 2$. On the left-hand side f varies and $t = 2$; and on the right-hand side t varies and $f = 2$. These parameter values do not, however, determine the equilibrium land configuration.

Transport costs also have an influence on the size of x_A. When transport costs are low, the incentives to locate close to the CBD decrease because the terminals have a relatively easy access. Higher transport costs, however, yield a fiercer land competition that gives rise to a lower x_A.

We can study these effects more thoroughly by looking at the effects of f and t on the bid-rent functions.

First, we concentrate on facility intensity (f). A rise in f yields a fall in k (since $k = \frac{g}{f}$) and then $R_a^*(x)$ decreases and $S_a^*(x)$ increases, whereas $R_i^*(x)$ and $S_i^*(x)$ remain unaffected. As a consequence, x_A decreases, as pointed out above. Thus, there is a clear inverse relationship between the facility intensity and the size of the airport at the land equilibrium. In a similar way, when the price of non-aviation services (g) increases, k also increases and thus x_A expands.

Let us now consider the case when the per-mile transport costs (t) rises. When t increases, transport is more expensive both for firms and service operators, and then their willingness to pay for land rent decreases implying a fall in both bid-rent functions. We observe, however, that the effect on service operators is stronger than the effect on firms and, as a consequence, the value of x_A decreases as transport costs increase as shown before.

These results are summarized in the proposition below.

Proposition 2 *At the equilibrium, industrial parks expand and airports shrink when (i) the facility intensity increases; (ii) transport costs increase; and (iii) the price of non-aviation costs decreases.*

In other words, when service operators and firms compete for land, large industrial parks are more likely to arise in areas where transport is expensive and non-aviation services are cheap; and there is a high facility intensity. The positive effect of facilities and the negative effect of non-aviation costs on firm location are quite intuitive. Nevertheless, the fact that an expensive transport fosters the formation of industrial parks seems to be less clear at first sight. It is reasonable to think, however, that the cheap transport options create incentives for firms to settle farther from the CBD since it looses its power of attraction.

As a consequence, non-exploited areas surrounding airports where there are not mature infrastructures and transport are still expensive are locations prone to become industrial parks. Furthermore, this phenomenon will be naturally encouraged by the presence of facilities and cheap non-aviation services. These particular land configurations are what Kasarda (2000) named *aerotropolis* (airport city), and seem to appear around relatively small cargo airports, surrounded by non-exploited low-density areas where land is so cheap that firms can occupy larger land plots.

Thus, our result confirms the evidence from Memphis (MEM) and Louisville (SDF) which have developed aerotropoli around the airport terminals in non-exploited areas characterized by the presence of some kind of external economies of scale (facilities in our terminology).

This exercise has also been performed for the case of a constant ex-ante density function ($n_a(x) = n_i(x) = 1$), and it is presented in Appendix B.

4 The Spanish case: a couple of case studies

Since the cases of Memphis (MEM) and Louisville (SDF) are clear *aeropolitan* configurations, we study in this section the cases of a couple of Spanish airport areas to try to analyze the possibility of having these kind of configurations outside the US. The selected airports are Madrid-Barajas (MAD) and Vitoria-Foronda (VIT).[20] In Spain, MAD is the most important passenger airport; and VIT is the most specialized cargo airport.

[20] Data from AENA's Annual Report (2004).

MAD combines passenger and cargo activities. In 2004, MAD recorded traffic of 38.71 million passengers and 0.34 million linear metric tons of delivered goods. As regards the cargo activities, the type of companies that mainly operate in MAD are the so called *combination carriers* which transport both passengers and goods.

VIT is the third Spanish cargo airport after MAD and Barcelona-El Prat (BCN). In 2004, VIT recorded a traffic of 0.095 million passengers and 0.04 million linear metric tons of delivered goods. VIT is the base for *integrated carriers* like FedEx, DHL and TNT that provide door-to-door express-delivery service.

- **Madrid-Barajas (MAD).** This airport area is around 39,000,000 sqm.[21] The most striking feature of its surroundings of this airport is the high number of industrial parks scattered randomly around. This feature makes it difficult to establish a clear-cut space scheme. According to the data supplied by the Madrid Development Institute (IMADE)[22] and the Madrid Chamber of Commerce,[23] the industrial parks surrounding MAD within a radius of 25 km are located (on average) at 14.13 km from the airport (Figure 3*a*). As the distance from the airport increases (within a radius of 40 km), the spatial distribution

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

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

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

becomes less clear (Figure 3*b*).

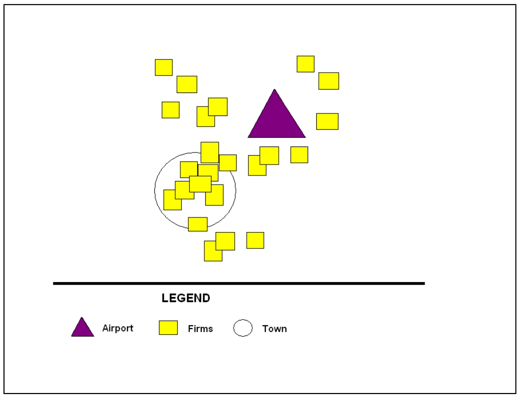

Figure 3*a*

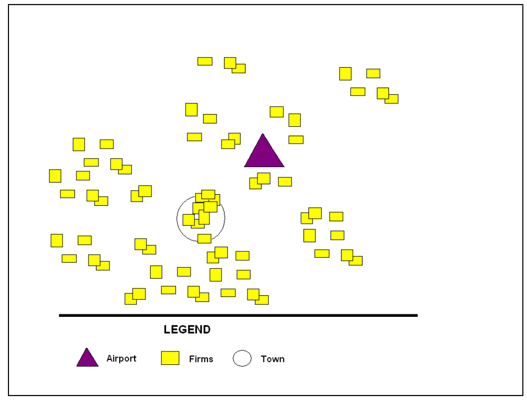

Figure 3*b*

- **Vitoria-Foronda (VIT).** The airport covers an area of 150,000 sqm in the proximity of Vitoria's industrial area. According to the information supplied by the Alava Development Agency,[24] the spatial distribution of activities follows this pattern:

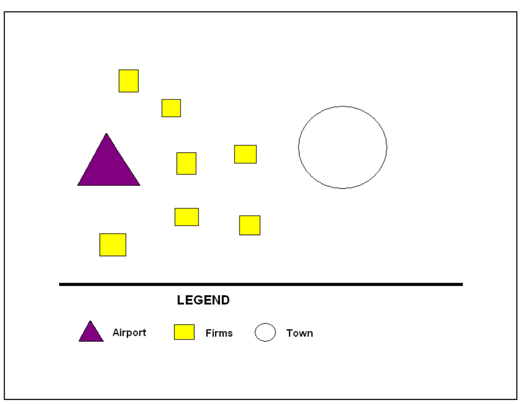

Figure 4*a*

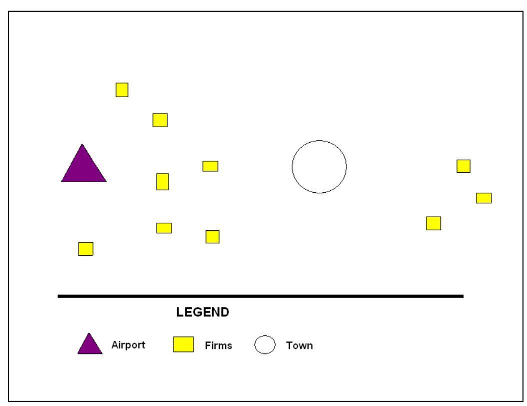

Figure 4*b*

[24] "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*).

If we take VIT airport as the reference point and focus on the space located within a radius of 25 km, the land distribution seems to adapt to the **A**-**I**-**R** scheme.[25] The industrial parks surrounding VIT are located (on average) at 13.12 km away from the airport, and are thus closer than the industrial parks around MAD (Figure 4*a*). When we enlarge the radius to 40 km, new industrial agglomerations appear and seem to be located closer to the town than the airport (Figure 4*b*). In case of VIT, however, the **A**-**I**-**R** land equilibrium is observed approximately up to a radius of 25 km assuming the airport as CBD. For greater distances, we need to address other arguments in order to explain land configuration.

Thus, the case of VIT seems to be closer to our theoretical land equilibrium characterized by the sequence **A**-**I**-**R**. The point that seems more difficult to assess is whether the industrial parks located in the surroundings of VIT could be considered an aerotropolis. What we can state is that it seems more likely we will observe an aerotropolis configuration (if any) around VIT than around MAD. Taking a closer look at VIT surroundings, we see that this is a mature region in terms of infrastructures where there are surely some external economies (or facilities). This case is difficult to assess since labelling an industrial area as an aerotropolis seems to be a matter of degree.[26]

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

[26] Given the current available data, it is difficult to compute an indicator of firm density in the surroundings of an airport. One possibility is to consider as an indicator of firm density the ratio between the number of firms and the total land they occupy. This indicator takes values of 0.008 for VIT and 0.007 for MAD within a radius of 25 km; these values shrink to 0.006 and 0.005 respectively within a radius of 40 km. This evidence seems to support the idea of a decreasing density with respect to the distance to the CBD, but, richer data are needed to elaborate a more detailed analysis.

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.[27] 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 commercial activities in the surroundings of certain airports.

Land competition around airports takes place among service operators, firms and farmers, when 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 constitute a key factor explaining land distribution. We find out that there is a unique land equilibrium characterized by the spatial sequence Airport - Industrial park - Rural area (**A**-**I**-**R**). Then, we find out that aerotropolis land configurations appear in non-exploited places where there are not mature infrastructures and transport is still expensive; and there is a high facility intensity (or external economies of scale).

Air-express "mega-hubs" such as Memphis (MEM) and Louisville (SDF) have developed around them some important industrial areas that seem to comply with these features. In Europe, we take a closer look at the Spanish market by studying the cases of Madrid-Barajas (MAD) and Vitoria-Foronda (VIT). In the first case, it seems evident that the possibility of having an aerotropolis can be disregarded. In fact, given their commercial orientation, aeropolitan areas

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

seem to be exclusive to cargo airports. The case of VIT is more difficult to assess since labeling an industrial area as an aerotropolis is a matter of degree.

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. In fact, nowadays it seems that there are some examples of *aerotropolis under construction* like "Las Colinas" located around Dallas-Ft. Worth area (DFW)[28] and, at a lower scale, the logistically integrated area "PLAZA" in Zaragoza (Spain).[29] Thus, 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 would be to adapt it for studying the importance of creating logistic and/or industrial areas in the proximity of transport hubs such as railways stations or harbors. We have developed an idea by looking at the specific case of an airport, but these results can easily be extended to other transportation infrastructures. From

[28] "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 seventy-five restaurants. Companies such as AT&T, Hewlett-Packard, Exxon, Abbot Laboratories, GTE and Microsoft are already there (Kasarda, 2000). See *http://en.wikipedia.org/wiki/Las_Colinas#Las_Colinas_today.*

[29] See *http://www.plazalogistica.com/index.aspx.*

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 should still uphold our conclusions. 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.

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A Appendix A: proof of Proposition 1

The equilibrium bid-rent functions of service operators and firms (expressions (6) and (8)) can be rewritten as

$$R_i^*(x) = \gamma(p-d)\left[\frac{d(1-\beta)(1+w)}{wt[(1-w)+(1-\beta)(1+w)]}\right]^{\frac{1-\gamma}{\gamma}} \frac{1}{x^{\frac{1-\gamma}{\gamma}}} \text{ and}$$

$$R_a^*(x) = \beta\left[k(1+w)\right]^{\frac{1}{\beta}} \left[\frac{(1-\beta)}{t(1-w)}\right]^{\frac{1-\beta}{\beta}} \frac{1}{x^{\frac{1-\gamma}{\beta}}},$$

and cross only once at positive point x_A given by expression (11). This is the only point equalizing the two bid-rent functions (single-crossing condition) because both $R_i^*(x)$ and $R_a^*(x)$ are decreasing and convex with x:

- $\frac{\partial R_i^*(x)}{\partial x} = \gamma(p-d)\left[\frac{d(1-\beta)(1+w)}{wt[(1-w)+(1-\beta)(1+w)]}\right]^{\frac{1-\gamma}{\gamma}} \left(\frac{\gamma-1}{\gamma}\right) x^{-\frac{1}{\gamma}}$, which is negative because $p > d$ and $w, \gamma, \beta \in (0,1)$. Hence $R_i^*(x)$ is downward sloping.
- $\frac{\partial^2 R_i^*(x)}{\partial x^2} = \gamma(p-d)\left[\frac{d(1-\beta)(1+w)}{wt[(1-w)+(1-\beta)(1+w)]}\right]^{\frac{1-\gamma}{\gamma}} \left(\frac{1-\gamma}{\gamma^2}\right) x^{-\frac{1+\gamma}{\gamma}}$, which is positive and thus $R_i^*(x)$ is convex.
- $\frac{\partial R_a^*(x)}{\partial x} = \beta\left[k(1+w)\right]^{\frac{1}{\beta}} \left[\frac{(1-\beta)}{t(1-w)}\right]^{\frac{1-\beta}{\beta}} \left(\frac{\gamma-1}{\beta}\right) x^{-\frac{1+\beta-\gamma}{\beta}}$, which is negative and consequently $R_a^*(x)$ is downward sloping.
- $\frac{\partial^2 R_a^*(x)}{\partial x^2} = \beta\left[k(1+w)\right]^{\frac{1}{\beta}} \left[\frac{(1-\beta)}{t(1-w)}\right]^{\frac{1-\beta}{\beta}} \left(\frac{\gamma-1}{\beta}\right)\left(\frac{\gamma-1-\beta}{\beta}\right) x^{-\frac{1+2\beta-\gamma}{\beta}}$, which is positive and therefore $R_a^*(x)$ is convex.

In fact, the convexity of $R_i^*(x)$ and $R_a^*(x)$ is determined by $\frac{1-\gamma}{\gamma}$ and $\frac{1-\gamma}{\beta}$ respectively, and it is easy to check that $R_a^*(x) > R_i^*(x)$ for $x < x_A$ and $R_a^*(x) < R_i^*(x)$ for $x > x_A$ requires $\beta < \gamma$, which is always observed. Finally, $\overline{R}_f^*$ and $R_i^*(x)$ cross once at x_I, with $0 < x_A < x_I$, as long as $\overline{R}_f^*$ remains sufficiently low.

B Appendix B: the case of a constant ex-ante density function

Differently to the decreasing-with-distance density assumed in the main text, we consider in this Appendix the case of a constant density function (i.e., independent with respect to distance). For sake of simplicity we normalize this density to one, so that $n_a(x) = n_i(x) = 1 \ \forall x \in X$. The results under this specification are qualitatively similar to those presented in the main text, although there are some nuances that are specified below.

In this case, profit functions become

$$\pi_i'(x) = \underbrace{(p-d)S_i'(x)^\gamma}_{Aviation\ profits} - \underbrace{R_i'(x)S_i'(x)}_{Land\ rent} - \underbrace{kS_a'(x)^\beta}_{Non\text{-}aviation\ costs} - \underbrace{tx}_{Transport\ costs} \quad \text{and}$$

$$\pi_a'(x) = \underbrace{dS_i'(x)^\gamma}_{Aviation\ revenues} - \underbrace{R_a'(x)S_a'(x)}_{Land\ rent} + \underbrace{kS_a'(x)^\beta}_{Non\text{-}aviation\ revenues} - \underbrace{tx}_{Transport\ costs},$$

where primes denote variables under the constant-density specification.

The equilibrium bid-rent functions are given by

$$R_a'^*(x) = \beta\left[k(1+w)\right]^{\frac{1}{\beta}}\left[\frac{(1-\beta)}{tx(1-w)}\right]^{\frac{1-\beta}{\beta}} \quad \text{and}$$

$$R_i'^*(x) = \gamma(p-d)\left[\frac{d(1-\beta)(1+w)}{wtx[(1-w)+(1-\beta)(1+w)]}\right]^{\frac{1-\gamma}{\gamma}},$$

and these functions are continuous, monotonic, downward slopping and cross only once at

$$x'_A = \left(\frac{(1-\beta)(1+w)}{t}\right)\left(\frac{\beta k(1+w)}{\gamma(p-d)}\frac{\left(\frac{w(2-\beta(1+w))}{d}\right)^{\frac{1-\gamma}{\gamma}}}{\left(\frac{(1-w)}{k}\right)^{\frac{1-\beta}{\beta}}}\right)^{\frac{\gamma\beta}{\gamma-\beta}}.$$

Thus, there is a unique land equilibrium characterized by the sequence **A**-**I**-**R** for a sufficiently low $\overline{R}'^{*}_{f}$ (the proof of the single-crossing condition is available from the authors upon request).

Although the comparative statics are similar to the ones under decreasing-with-distance density, there are some quantitative differences in terms of the intensity for land competition. Looking at the effects of the facility intensity and per-mile transport costs on the limit of the airport area in both cases, we observe that competition is softer under the constant-density specification, as shown in Figure 5 below.[30]

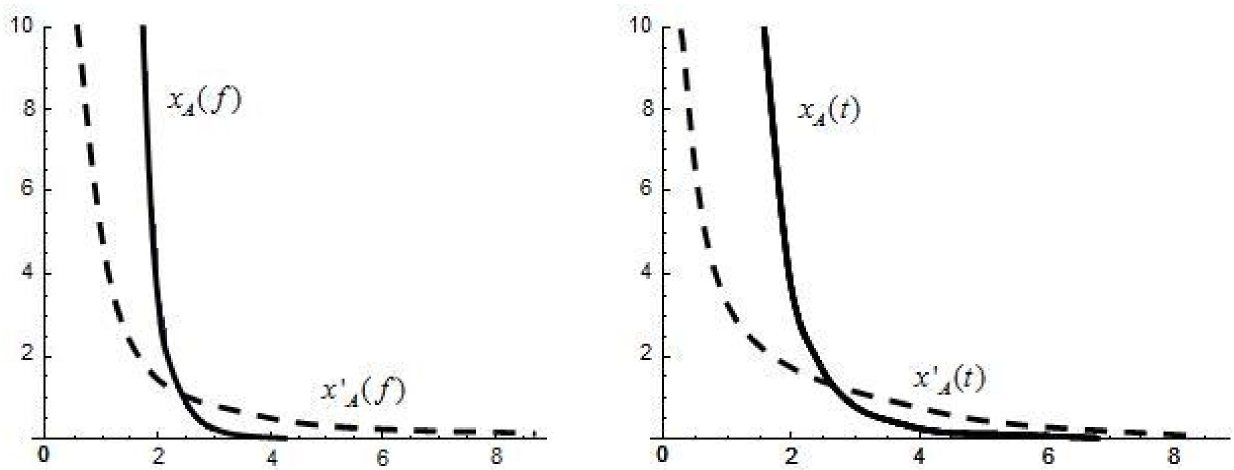

Figure 5: $x'_A(f)$ and $x'_A(t)$

[30] These two figures are drawn by selection of the following parameter values: $\gamma = 3/4$, $\beta = 1/3$, $p = 6$, $d = 1$ and $g = 2$. On the left-hand side f varies and $t = 2$; and on the right-hand side t varies and $f = 2$. These parameter values, however, do not determine the equilibrium land configuration.

With a decreasing-with-distance ex-ante density, land competition is fiercer because of the larger concentration of agents in the land plots close to the CBD before the bidding process. As a consequence, the size of the airport is comparatively smaller.