R&D and Strategic Industrial Location in International Oligopolies

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Abstract

In a spatial economy where oligopolist firms compete in R&D, it is found that geography affects the innovative behavior of firms. Notably, international differences in market size conduce to endogenous asymmetries between firms given that firms located in the country with more demand have stronger incentives to invest in R&D. This "R&D linkage" between demand and competitiveness promotes firms to strategically delocalize to the larger country. As a result, a spatial equilibrium arises with only total or partial agglomeration, but never with symmetric dispersion.

Keywords: Industrial Location, Oligopoly, R&D Investment, Asymmetric Firms, Agglomeration Effects.

JEL Classification: F12, L13, O31, R3.

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1 Introduction

Technological innovation is undoubtedly central for modern economic organization and international competition. However, one of the outstanding characteristics of R&D is that it is highly concentrated in very few countries. Moreover this is not just a North-South phenomenon but is also the case amongst developed countries. For example in 2003 the US alone accounted for 43% of business R&D expenditure in the OECD area (OECD, 2005). If Japan and Germany are also added, then, this figure goes up to 70%.

Having this simple evidence in mind the objective of the paper is two-fold: *i)* to look at some of the factors that can contribute to firms from different countries investing more in R&D; *ii)* to investigate how firms' location decisions can be affected by international R&D patterns.

To accomplish this, Brander's (1981) two-way trade model is extended to incorporate process R&D as in Leahy and Neary (1997) in a spatial economy closer in spirit to Krugman (1991) and Ottaviano et al. (2002). Brander's (1981) formalization allows for introduction of competition amongst oligopolist firms. As recent empirical literature suggests (see Tybout, 2003) international competition is mainly driven by market structures of this type. Process R&D is modeled as reducing marginal costs at the same time as it increases fixed costs. As such, when firms invest in R&D they face a trade-off between lower marginal costs and higher fixed costs.

In turn, as in the "new" economic geography (NEG), the spatial dimension is introduced via trade costs[1]. It is further assumed that firms and workers move respectively to the country that gives them higher profits or welfare. Then there are two distinct sources of regional growth: migration by workers and delocalization by firms. This is the opposite of what is standard in the NEG labor migration case (as Krugman, 1991) where workers' and firms' spatial movements are directly connected through the labor market clearing condition. What this implies is that in the NEG labor migration models, firms delocalization choices mimic exactly workers' migration patterns. Given that what motivates workers to migrate might not be what induces firms to delocalize, in this paper these decisions are not so directly related in order to see the interconnections between the two.

This set-up allows us to tackle the two issues at the core of this paper (see three paragraphs above). To be precise, it gives an answer to the first prob-

[1]For a review on the NEG monopolistic competition models see Neary (2001).

lem since it brings in endogenous asymmetries between firms: firms located in the country with more demand are more efficient given that they have stronger strategic incentives to perform higher levels of R&D[2]. This happens because in larger countries the trade-off that a firm faces when it invests in R&D (lower marginal costs *versus* higher fixed costs) is more easily met. In turn, this "R&D linkage" between demand and competitiveness, provides an answer to the second problem: firms want to locate in the larger country since there they can invest more in R&D. Hence, delocalization decisions by firms are strategic. In what refers to workers, as in the NEG, they prefer locations with more firms, because competition drives prices down increasing real wages. In the end, interconnections between firms and workers localization decisions can lead to "cumulative causation" effects that promote agglomeration of economic activity.

The framework adopted here also permits us to both endogenize location and to introduce strategic interactions between firms. Location is endogenous as a result of migration by workers, delocalization by firms and international technological competition that can change the spatial economic characteristics of competitive countries. Firms interact strategically, given that they play Cournot and invest in R&D. Note that this is not the case in the two best known economic models of industrial location: Hotelling (1929) and NEG. Conversely, in the NEG, locations can endogenously differentiate from one another in terms of demand patterns and resource efficiency due to migration by workers (Krugman, 1991) or vertical linkages between firms (Venables, 1996). Nonetheless, it ignores strategic competitive aspects since monopolistic competitive firms are 'myopic' about rivals. In turn, in Hotelling, location is exogenous due to the fact that each point in the line is equal to all remaining points and nothing can change this symmetry, although, firms play a strategic Bertrand price competition game.

In this sense, this paper relates only partially to Hotelling spatial oligopoly models such as Anderson and Neven (1991) or NEG growth models such as Martin and Ottaviano (2001). Anderson and Neven (1991) introduce Cournot competition in the Hotelling location problem. Martin and Ottaviano (2001), instead, merge the trade and growth literature (see Grossman and Helpman, 1995) with the NEG, i.e.: they consider a perfectly competi-

[2] This differs from Melitz (2003) and Bernard et al. (2003) heterogeneous firms models, where asymmetries between firms are exogenously assumed *à priori* as a function of a statistical distribution.

tive R&D sector that creates new varieties to the monopolistic competition sector.

As such, this paper to Anderson and Neven (1991) adds R&D and substitutes a continuous space *à la* Hotelling (i.e.: the line) for a discrete space with two countries. It is true that the best way to model space depends on the context and type of issues approached. However, the discrete location case may fit international geography better since political borders create strong discontinuities in space as shown by recent empirical work (see Anderson and van Wincoop, 2004). Compared to Martin and Ottaviano (2001), market structure in this paper is oligopoly instead of monopolistic competition, and R&D is performed by firms themselves and not by an outside sector. For that reason, here R&D competition between firms is central, while in Martin and Ottaviano (2001) it is down played so as to consider other types of dynamic issues as growth.

The reminder of the paper consists of eight sections. Section 2 presents the oligopoly R&D location model and Section 3 solves for the production stage (R&D and outputs). Section 4 explores the agglomeration forces ("demand" and "R&D linkage" effects) while Section 5 investigates the dispersion forces ("competition" effects). Section 6 studies delocalization by firms and Section 7 analyzes migration by workers. Section 8 finds the spatial equilibrium of the model and Section 9 concludes by discussing results.

2 The Model

This section introduces an oligopolist trade model (*à la* Brander, 1981) where firms perform process R&D (like in Leahy and Neary, 1997) embedded in a spatial economy setting (following Ottaviano et al., 2002).

2.1 Basic Assumptions

The economy consists of two countries: home and foreign[3]; two sectors: the increasing returns oligopolist sector (IRS) and the constant returns perfect competition sector (CRS); and one factor of production: labor.

The CRS produces the CRS-good that can be freely trade between countries. This sector is kept in the background, since its role is to represent 'the

[3]An asterisk indicates foreign variables.

rest of the economy' and also to assure that if an agglomeration phenomenon is in place, a country always keeps some economic activity.

Firms in the IRS compete in outputs and R&D to produce the IRS-good that is subject to *ad-valorem* trade costs when exchanged between countries. N is the total number of oligopolist firms, and $s \in (0,1)$ is the share of firms at home. Then, home hosts $sN = n$ firms, while foreign $(1-s)N = n^*$.

Also, M is the quantity of labor available in the world and r is the share of workers at home, i.e.: rM is the number of workers at home (and $(1-r)M$ at foreign). Since workers are at the same time consumers, then, r also represents the share of demand at home.

Labor is divided into two components: immobile labor (A) and mobile labor (L). The former is country specific, while the latter is internationally mobile. It is further assumed that immobile workers are evenly distributed between countries: home and foreign have $A/2$ units of immobile labor. In turn, $u \in (0,1)$ denotes the share of mobile labor at home, i.e.: home hosts uL mobile labor (and foreign $(1-u)\,L$).

Then, $M = (A+L)$, $rM = A/2 + uL$ and $(1-r)M = A/2 + (1-u)\,L$. This means that r never equals zero or one and it is linear in u[4]. The objective of this set-up is twofold: to access the effects of differences in size between countries on R&D patterns; and like in the NEG, to allow some workers to be subjected to agglomeration forces.

2.2 Preferences and Demand

Preferences are quasi-linear in the two goods, with a quadratic sub-utility in the IRS-good:

$$U = aQ - \frac{b}{2}Q^2 + q_0 \tag{1}$$

where q_0 is production and consumption of the CRS-good and $Q = \sum_{i=1}^{n} q_i + \sum_{i=1}^{n^*} x_i^*$ home consumption of the IRS-good, with: q (q^*) sales of a representative home (foreign) firm to each consumer at home (foreign); and x (x^*) exports of a representative home (foreign) firm to each consumer at foreign (home). Also $a = a^*$, $b = b^*$ and $q_0 = q_0^*$.

[4] For this reason, throughout the paper equations will be mainly shown in terms of r and M (instead of u, L and A).

Each individual is endowed with a unit of labor (A or L) and $\bar{q}_0 > 0$ units of the CRS-good[5]. Then, consumers have as budget constraint:

$$PQ + q_0 = I + \bar{q}_0 \tag{2}$$

where P and I stand for the price level and income at home, respectively.

This maximization problem gives the following indirect demand, where a is the intercept of demand and b is an inverse measure of market size:

$$P = a - bQ \tag{3}$$

It is also possible to derive the indirect utility function by substituting for Q (from equation 3) and q_0 (from equation 2) in equation 1 to obtain:

$$V = \frac{a^2}{2b} - \frac{a}{b}P + \frac{1}{2b}P^2 + I + \bar{q}_0 \tag{4}$$

2.3 Firms and Technology

Technology in the CRS requires one unit of labor (M) to produce one unit of output. Therefore, as long as this sector produces positive output, the economy wide wages are fixed relatively to the price of the CRS-good. We then set nominal wages in both countries to one: $w = w^* = 1$[6]. This shuts down one channel for workers' agglomeration: wage differentials between countries. However, given that this agglomeration channel was already extensively explored by the NEG, this paper abstracts from it[7]. The objective of this simplification, besides analytical convenience, is to concentrate solely on the role of R&D in the location dynamics of firms and workers.

In turn, technology in the IRS enters through the marginal and fixed costs of production (respectively C and Γ). Production costs are central because

[5]This assumption is made in order to guarantee that the consumption of the CRS-good is always positive (see Ottaviano *et al.*, 2002).

[6]As a result this model is in partial equilibrium. This is so for two reasons. First, factor markets are not explicitly modeled since wages are fixed. Second, due to quasi-linear preferences, income effects do not apply to the IRS-good. Note however that it is not consensual in the literature how to model oligopolies in general equilibrium. For a new and more convincing formalization see Neary (2002).

[7]The assumption of fixed wages also occurs in some NEG models such as Venables (1996).

it is through them that R&D is introduced[8]. Specifically, as in Leahy and Neary (1997) it is considered process R&D:

$$C_i = c - \theta k_i \tag{5}$$
$$\Gamma_i = \gamma \frac{k_i^2}{2} \tag{6}$$

Where k_i is R&D conducted by a representative home firm (and k_j^* for a foreign firm); θ is the cost-reducing effect of R&D; γ is the cost of R&D; and c is the initial marginal costs. Also, $\theta = \theta^* > 0$, $\gamma = \gamma^* > 0$, and $c = c^* > 0$, i.e.: home and foreign firms are symmetric in terms of technology parameters.

Then, process R&D reduces marginal costs by θk, but it increases fixed costs by $\gamma k_i^2/2$. In other words, the decision to invest in R&D faces a trade-off between lower marginal costs but higher fixed costs.

Profits by a representative home firm in the IRS can then be defined as:

$$\Pi_i = (P - C_i)\, rMq_i + (P^* - C_i - t)\,(1-r)\, Mx_i - \Gamma_i \tag{7}$$

where t are the specific per-unit transport costs (with $t = t^*$, i.e.: home and foreign firms bear the same trade costs).

2.4 Space

The location game considers two stages: in stage 1 mobile workers and firms make their location decisions simultaneously; in stage 2 firms choose R&D and outputs levels. The game, as usual, is solved by backward-induction.

In what refers to the spatial dimension, mobile workers choose location based on utility levels, while firms select on the basis of profits. Conversely, firms and mobile workers move automatically in response to profit and indirect utility differentials between countries, respectively. In other words, firms delocalize to where they can get higher profits and mobile workers to where utility is higher. To model this, $\Delta\Pi$ is defined as the difference in profits that a representative firm can obtain from being located at home or at foreign:

$$\Delta\Pi\,(s,u) = \Pi\,(s,u) - \Pi^*\,(s,u) \tag{8}$$

[8] In this way, the main difference between this paper and other standard Cournot models (as Brander, 1981) is the cost function.

Then, if $\Delta\Pi = 0$, delocalization is not promoted; if $\Delta\Pi > 0$, firms move to home; if $\Delta\Pi < 0$, firms delocalize to foreign.

Analogously ΔV is defined as the difference in the indirect utility that a mobile worker can obtain from living at home or at foreign[9]:

$$\Delta V(s,u) = V(s,u) - V^*(s,u) \tag{9}$$

Thus, if $\Delta V = 0$, migration is not encouraged; if $\Delta V > 0$, mobile workers move to home; if $\Delta V < 0$, mobile workers migrate to foreign[10].

3 Production Equilibrium

This section presents the production equilibrium of the R&D model above. Since firms are (initially) symmetric and markets are segmented, then: $q_i = q_j$, $x_i = x_j$ and $k_i = k_j$ for $\forall$ i and j firms from home (and also $q_i^* = q_j^*$, $x_i^* = x_j^*$ and $k_i^* = k_j^*$ for $\forall$ i and j firms from foreign). In this way outputs equal (see appendix):

$$\begin{aligned}
q &= \frac{(N+1)((1-\eta)D+(1-s)Nt)-(1-r)t\eta(2(1-s)N(N+2-\eta)+(1-\eta))}{b((N+1)-\eta)(1-\eta)(N+1)} \\
x &= \frac{(N+1)((1-\eta)(D-t)-(1-s)Nt)+rt\eta(2(1-s)N(N+2-\eta)+(1-\eta))}{b((N+1)-\eta)(1-\eta)(N+1)} \\
q^* &= \frac{(N+1)((1-\eta)D+sNt)-rt\eta(2sN(N+2-\eta)+(1-\eta))}{b((N+1)-\eta)(1-\eta)(N+1)} \\
x^* &= \frac{(N+1)((1-\eta)(D-t)-sNt)+(1-r)t\eta(2sN(N+2-\eta)+(1-\eta))}{b((N+1)-\eta)(1-\eta)(N+1)}
\end{aligned} \tag{10}$$

where $D = (a-c)$ is a measure of the initial cost competitiveness of firms. We restrict the parameter space to $D > t > 0$ so that even without R&D investment all firms can face trade costs. In turn, $\eta = \theta^2 M/b\gamma$ is like in Leahy and Neary (1997) an indicator of the "relative return to R&D". A high η represents a large return on innovative activities, since the cost-reducing

[9]Since $w = w^* = 1$, ΔV depends only on P and P^*. Then, prices are central in what concerns migration decisions by workers, i.e.: nominal wages are fixed but the same is not the case for real wages, given that price levels can vary between countries. It is this that can trigger migration movements by workers.

[10]Naturally, corners are stopping conditions, i.e.: at $s = 1$ ($s = 0$) even if $\Delta\Pi > 0$ ($\Delta\Pi < 0$) firms do not move to home (foreign) anymore because all firms are already located there; also, at $u = 1$ ($u = 0$) if $\Delta V > 0$ ($\Delta V < 0$) mobile workers stop moving to home (foreign).

effect of R&D (θ), weighted by M/b (market size and population), is large relatively to its cost (γ). The reverse interpretation holds for low η.

In turn for R&D the solution is (see appendix):

$$\begin{aligned} k &= \theta M \tfrac{(1-\eta)(D-t(1-r))+Nt(1-s)(2r-1)}{\gamma b((N+1)-\eta)(1-\eta)} \\ k^* &= \theta M \tfrac{(1-\eta)(D-rt)-sNt(2r-1)}{\gamma b((N+1)-\eta)(1-\eta)} \end{aligned} \tag{11}$$

Then, k and k^* depend on the relative size of the local and the foreign demand markets (r), i.e.: geography. Below the exact relation between demand patterns and R&D investment will be investigated.

For prices instead:

$$\begin{aligned} P &= c + \tfrac{(N+1)(D+(1-s)Nt)-\eta\left(D(N+1)-2Nt(1-r)\left(s-\frac{1}{2}\right)\right)}{((N+1)-\eta)(N+1)} \\ P^* &= c + \tfrac{(N+1)(D+sNt)-\eta\left(D(N+1)+2Ntr\left(s-\frac{1}{2}\right)\right)}{((N+1)-\eta)(N+1)} \end{aligned} \tag{12}$$

Before concluding this section some final remarks related with the parameter η. It will be seen throughout the paper that η is central to the analysis. In fact, a stability condition for this parameter is required so that firms do not have any incentives to invest infinitely in R&D in order to attain negative marginal costs. Consequently the following is assumed:

$$0 < \eta < 1 \tag{13}$$

Equation 13 says that the cost-reducing effect of R&D weighted by market size and the number of consumers in the world economy cannot be bigger than the cost of R&D. Conversely, if γ is not sufficiently high relatively to θ, $1/b$ and M, the trade-off that a firm faces when investing in R&D (lower marginal costs *versus* higher fixed costs) is not binding[11].

[11] Actually, if equation 13 is not satisfied, outputs and R&D may be negative. To see this, make the following thought experiment: imagine that home hosts all world demand (i.e.: $r = 1$), then if $0 < \eta < 1$, $q > 0$; if $\eta > (N+1)$, $q < 0$; if $1 < \eta < (N+1)$, q can be either positive or negative. Then, in case that $\eta > 1$, even when a country hosts all demand, local sales might be negative. Also as will be seen below, if equation 13 does not hold, comparative static results and the model previsions do not make much economic sense.

4 Agglomeration Forces: Demand and R&D Linkage Effects

This section looks at the centripetal forces that firms in the R&D model are subjected to: "demand" and "R&D linkage" effects.

4.1 Demand Linkage Effect

The mechanism at work in the "demand linkage" effect is the same as in the NEG: firms are encouraged to delocalize to the country that hosts a higher share of demand, since there, sales (and potentially profits) are higher. To see this, look at the derivatives of q and x in relation to r:

$$\frac{dq}{dr} = \frac{dx}{dr} = \eta t \frac{2N(1-s)((N+2)-\eta)+(1-\eta)}{b((N+1)-\eta)(1-\eta)(N+1)} > 0 \tag{14}$$

As long as $0 < \eta < 1$ these two derivatives are equal and always positive showing that "demand" effects contribute positively to profits.

Proposition 1 *In an international oligopolist market, firms from the country with more demand have higher sales. Thus, demand linkage effects create incentives for firms to delocalize (agglomerate) to the larger country.*

Note that the symmetry in this model implies that when the local share of demand increases at home, it decreases at foreign by the same amount. This raises the question of why home exports increase with the home share of demand, if when that is happening the foreign share of demand is decreasing? To clarify this, however, it is necessary to proceed to the "R&D linkage" effect.

4.2 R&D Linkage Effect

The "R&D linkage" effect explains how geography affects the innovative behavior of firms and *vice-versa*. To see this, look at the difference between R&D performed by a representative home firm and a representative foreign firm:

$$k - k^* = 2\left(r - \frac{1}{2}\right) t \frac{\theta M}{\gamma b(1-\eta)} \tag{15}$$

As long as equation 13 holds: $k = k^*$ if $r = 1/2$; $k > k^*$ if $r > 1/2$; and $k < k^*$ if $r < 1/2$. Thus, firms located in the larger country invest more in R&D, which makes them more competitive than firms from the smaller country. In this sense, demand patterns by promoting strategic responses in R&D can produce endogenous asymmetries between firms from different countries. The rational for this follows from the R&D trade-off: lower marginal costs against higher fixed costs. Conversely, this trade-off is more easily met (i.e.: R&D is more profitable) the larger the local market.

Proposition 2 *In an international oligopolist market, firms from the country with more demand invest more in R&D. This R&D linkage between demand and competitiveness encourages firms to delocalize (agglomerate) to the larger country.*

Hence, this endogenous asymmetry property of the R&D model is of great importance, because it may possibly spur agglomeration of the oligopolist sector. Furthermore, and contrary to the "demand" effect that comes only from the demand side, the "R&D linkage" effect, in spite of being triggered by demand, also ensues from the supply side given that it is the result of explicit R&D decisions by firms. This means that R&D strategies have the power to affect economic geography since it influences firms' location choices. However, once the reverse is also true (i.e.: geography influences the innovative behavior of firms) the location decisions of firms are also strategic[12].

Now it is also possible to understand why $dx/dr > 0$. The rational is that when r increases, k also increases, and as a result home firms become more competitive than foreign rivals. In fact, this "competitiveness" effect in R&D is so strong that it even allows home firms to surpass the trade cost disadvantage in the foreign market and increase exports *per* consumer[13].

5 Dispersion Forces: Competition Effects

Similarly to the NEG, the main centrifugal force for firms in the R&D model is the local level of competition: as domestic rivalry increases, prices go down

[12] This is not the case in the NEG where only external market conditions can create conditions for agglomeration to take place.

[13] In the same way, the explanation for $dq/dr > 0$ can now be completed. When r increases, it is not only domestic demand that increases, but also the competitiveness of local firms that keeps less efficient foreign rivals away from the domestic market.

cannibalizing the profits of local firms. To see this, look at the derivative of P in relation to s:

$$\frac{dP}{ds} = -Nt\frac{(N+1)-2\eta(1-r)}{((N+1)-\eta)(N+1)} < 0 \qquad (16)$$

It can be easily checked that this derivative is unambiguously negative. Therefore, when the share of firms in one location increases, agglomeration of firms can be discouraged.

Proposition 3 *In an international oligopolist market, as a result of competition effects, prices are lower in the country with more firms. This can promote firms to delocalize (disperse) to the country with fewer firms.*

Firms' location decisions, like in the NEG, result from the interplay of centripetal and centrifugal forces. Agglomeration of firms is promoted when the former are stronger than the latter, and dispersion is supported when the reverse happens. The following section analyzes these interactions.

6 Spatial Behavior of the Profit Differential

The two previous sections have studied the forces pro-agglomeration and pro-dispersion of firms. In this section, the spatial behavior of firms is explicitly investigated by looking at the profit differential equation. It can be checked that equation 8 can be simplified to:

$$\Delta\Pi = 2tM\frac{(1-\eta)(2-\eta)\left(D-\frac{t}{2}\right)\left(r-\frac{1}{2}\right)+\left[(1-\eta)\left(4\eta r(1-r)\left(1+\frac{1-\eta}{N+1}\right)-1\right)-2\eta\left(r-\frac{1}{2}\right)^2\right]Nt\left(s-\frac{1}{2}\right)}{(1-\eta)^2((N+1)-\eta)} \qquad (17)$$

The denominator of this expression is always positive as long as $0 < \eta < 1$. Then, to sign $\Delta\Pi$ it is just necessary to study the nominator: the first term is positive for $r > 1/2$, negative for $r < 1/2$, and zero for $r = 1/2$; the second term is positive for $s < 1/2$, negative for $s > 1/2$, and zero for $s = 1/2$ (see proof in appendix).

Conversely, the first term represents the positive effect that domestic demand has on the competitiveness and on the sales of local firms and the second term is the negative effect of domestic competition on local prices. From the interaction of these two terms five cases can be identified.

Case 0: $r = s = 1/2 \Rightarrow \Delta\Pi = 0$ All terms cancel out and then $\Delta\Pi = 0$.

Case 1: $r > 1/2$ **and** $s > 1/2 \Rightarrow$ ***(i)*** $\Delta\Pi > 0$ **or** ***(ii)*** $\Delta\Pi < 0$ Since the first term is positive and the second negative, $\Delta\Pi > 0$ or $\Delta\Pi < 0$. $\Delta\Pi < 0$ if s and r are close to one and either: η is close to one, or N or t are sufficiently large or D is sufficiently small. $\Delta\Pi > 0$ when the reverse happens (even when s and r tend to one). See proof in appendix.

Case 2: $r < 1/2$ **and** $s < 1/2 \Rightarrow$ ***(i)*** $\Delta\Pi < 0$ **or** ***(ii)*** $\Delta\Pi > 0$ Symmetric to Case 1.

Case 3: $r < 1/2$ **and** $s > 1/2 \Rightarrow \Delta\Pi < 0$ In this case all terms are negative and as such $\Delta\Pi < 0$.

Case 4: $r > 1/2$ **and** $s < 1/2 \Rightarrow \Delta\Pi > 0$ Symmetric to Case 3.

The rational for these different cases is now considered. If both demand and industry are evenly distributed (Case 0), then, total symmetry between countries and firms arises. As a result, firms have no incentives to move.

If home, comparatively to foreign, hosts a higher share of firms but a lower share of demand (Cases 3), then, both the "competition" effects (centrifugal forces) and "demand" and "R&D linkage" effects (centripetal forces) are negative and, as such, dispersion of firms is promoted. The reverse happens in Case 4.

Instead, if home has a higher share of demand but a lower share of firms than foreign (Case 1), two situations can emerge. In Case 1(i), "demand" and "R&D linkage" effects supplant "competition" effects and, thus, agglomeration of firms at home is encouraged. In turn, in Case 1(ii) the opposite occurs and, therefore, firms prefer dispersion. This can take place when trade costs, or the number of firms in the oligopolist sector, or the return on R&D are high[14], or firms' initial cost competitiveness is low. These scenarios imply strong competition: high t or low D makes exports less profitable; high N represents fierce competition; and large η creates strong incentives for firms to invest more in R&D to beat-up competition. The contrary comes about in Cases 2(i) and 2(ii).

[14] The return on R&D is high when market size and the return on R&D are large and the cost of R&D is low.

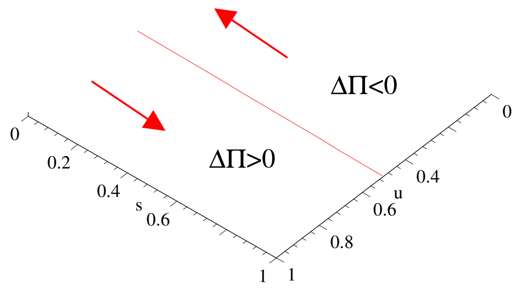

Figure 1: Contours $\Delta\Pi$: fairly low competition (Cases 1(i), 2(i), 3, 4)

As a result of these four cases, the profit differential equation can have two shapes in the (s,u) space (see figure 1 and figure 2[15])[16]. In figure 1 $\Delta\Pi$ is positive to the left of the isoline ($r > 1/2$) and negative to the right ($r < 1/2$). Then firms move to the location with more demand.

In figure 2 as in figure 1, $\Delta\Pi$ is positive to the left of the isoline and negative to the right. However, to the left of the isoline and for high values of s and u, $\Delta\Pi$ becomes negative; to the right of the isoline and for very low values of s and u, $\Delta\Pi$ turns positive. Then, when competition is very fierce, for very high (or very low) values of s and u firms stop moving to the country with more demand.

Proposition 4 *In an international oligopolist market, firms' location decisions depend on the relation between, on the one hand, demand and competitiveness effects on R&D, and on the other hand, competition effects. Firms move to the country with more demand when the former effects dominate the latter, but move away from the country with more demand and firms when the reverse happens.*

[15]Given that $r \neq 0$ and $r \neq 1$ these two figures and also the following ones are better defined in the (s,u) space, so that the two axes have the same origin.

[16]Figures 1 and 2 show the isolines for the profit differential (i.e.: $\Delta\Pi = 0$). Directional arrows indicate delocalization movements of firms.

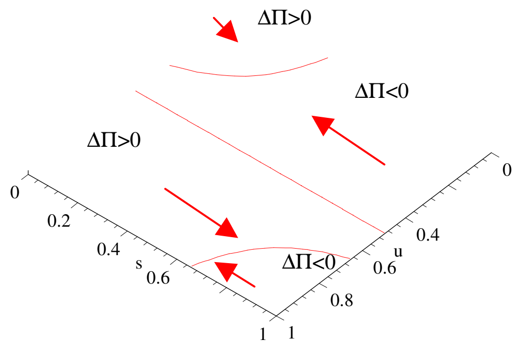

Figure 2: Contours $\Delta\Pi$: high competition (Cases 1(*ii*), 2(*ii*), 3, 4)

7 Spatial Behavior of the Indirect Utility Differential: Price Effects

This section studies the spatial behavior of mobile workers by looking at the indirect utility differential between locations (equation 9). The explicit expression for ΔV can be found by substituting for prices (P and P^*, equation 12) to obtain:

$$\Delta V = \left(s - \tfrac{1}{2}\right) 2N^2 t \frac{D(N+1) - \frac{t}{2}\left[(N+1) - 4\eta\left(s - \frac{1}{2}\right)\left(r - \frac{1}{2}\right)\right]}{(N+1)^2((N+1) - \eta)b} \tag{18}$$

The denominator of this expression is always positive as long as $0 < \eta < 1$. The same happens with the nominator as long as $D > t$ (see proof in appendix). Then $\Delta V > 0$ if $s > 1/2$; $\Delta V < 0$ if $s < 1/2$; and $\Delta V = 0$ if $s = 1/2$, i.e.: the country that hosts more firms attracts more mobile workers. This is so, because of "price" effects that result from the local level of competition: prices are lower (see equation 16) and, therefore, indirect utility is higher in the country with more industry. As a result the behavior of the indirect utility differential in the (s, u) space is as in figure 3[17].

Proposition 5 *In an international oligopolist market, workers favor locations with more firms, since due to price effects welfare is higher there.*

[17] Figure 3 shows the isoline of the indirect utility differential (i.e.: $\Delta V = 0$). Directional arrows indicate migration movements of mobile labor.

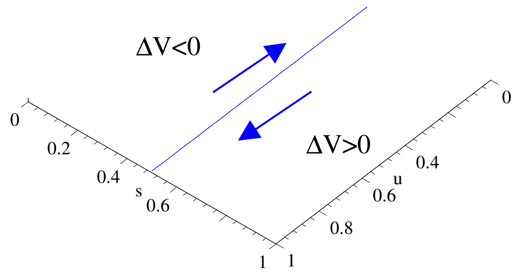

Figure 3: Contours ΔV

In this sense, the spatial behavior of workers and firms differs: firms like environments with low competition, while workers prefer the opposite. This shows why it is useful to separate the location decisions of different economic agents: only by doing so can differences in spatial preferences be uncovered.

8 Spatial Equilibrium

This section solves the R&D model for the first-stage, i.e.: location. Given that workers and firms locations decisions are separated, this model can potentially encompass the following spatial equilibriums:

$$\begin{gathered}\text{A: } \Delta V = \Delta\Pi = 0 \text{ for } \forall\ u \text{ and } s \in (0,1)\\ \text{B}(i)\text{: } \Delta V > 0 \text{ and } \Delta\Pi > 0 \text{ and } u = s = 1\\ \text{B}(ii)\text{: } \Delta V < 0 \text{ and } \Delta\Pi < 0 \text{ and } u = s = 0\\ \text{C}(i)\text{: } \Delta V > 0 \text{ and } \Delta\Pi = 0 \text{ and } u = 1 \text{ and } s \in (0,1)\\ \text{C}(ii)\text{: } \Delta V < 0 \text{ and } \Delta\Pi = 0 \text{ and } u = 0 \text{ and } s \in (0,1)\\ \text{D}(i)\text{: } \Delta V = 0 \text{ and } \Delta\Pi > 0 \text{ and } u \in (0,1) \text{ and } s = 1\\ \text{D}(ii)\text{: } \Delta V = 0 \text{ and } \Delta\Pi < 0 \text{ and } u \in (0,1) \text{ and } s = 0 \end{gathered} \tag{19}$$

A spatial equilibrium is then a point in the (s, u) space where firms and

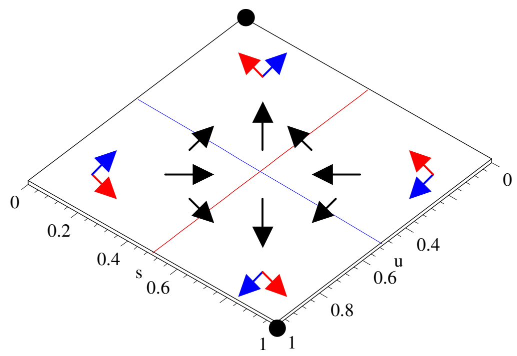

Figure 4: Spatial equilibrium: fairly low competition

workers have no incentives to move[18]. In addition, spatial equilibriums (A) to (D) are stable if for any marginal deviation from the equilibrium, workers and firms move back to the original point (see also appendix).

A simple way to find the solution of the location game is just to plot together the isolines of the profit differential and indirect utility differential equations. It is then straightforward to see that two types of spatial equilibriums configurations can arise. The first one is shown in figure 4, that is basically figure 1 plus figure 3[19].

The only stable spatial equilibrium in figure 4 is agglomeration at either home ($s = u = 1$) or foreign ($s = u = 0$). Conversely, the symmetric dispersed equilibrium is saddle-path stable and therefore has probability zero to arise (see Neary, 1978), i.e.: it is 'observational unstable' (proofs on stability are in appendix).

Figure 4 therefore shows the presence of "cumulative causation" effects. Specifically, from the part of firms' "demand" and "R&D linkage" effects, and from the part of mobile workers' "price" effects. This is illustrated in figure 5. If for example home starts to host more mobile workers, then "R&D linkage"

[18] Case A is a spatial equilibrium since $\Delta V = \Delta\Pi = 0$; B given that firms and workers are at a corner $u = s = 1$ ($u = s = 0$) and $\Delta V > 0$, $\Delta\Pi > 0$ ($\Delta V < 0$, $\Delta\Pi < 0$); C once $\Delta\Pi = 0$, and workers are at a corner $u = 1$ ($u = 0$) and $\Delta V > 0$ ($\Delta V < 0$); D because $\Delta V = 0$, and firms are at a corner $s = 1$ ($s = 0$) and $\Delta\Pi > 0$ ($\Delta\Pi < 0$).

[19] Besides the isolines and the directional arrows, figure 4 also shows: streamline arrows that map out location movements from any point in the (s, u) space; and black circles to represent stable spatial equilibriums.

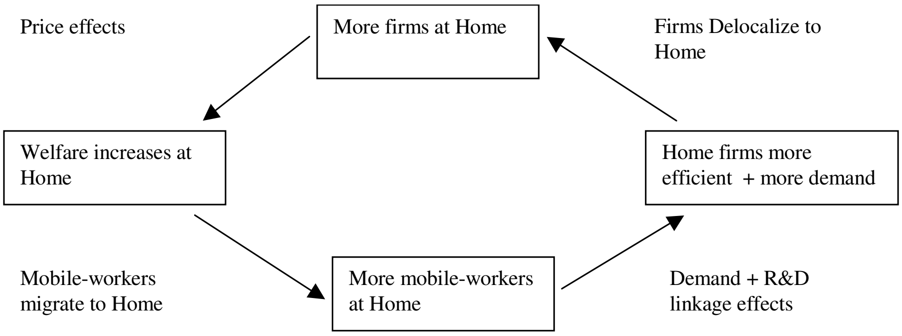

Figure 5: Cumulative causation effects

effects between innovation and demand make home firms endogenously more efficient than foreign firms. Moreover, as a result of "demand" effects home firms also benefit from higher sales comparatively to foreign rivals. Thus, "R&D linkage" effects together with "demand" effects lead to delocalization of firms from foreign to home. In turn, more firms located at home will increase the welfare of mobile workers due to "price" effects. This encourages further migration of mobile workers from foreign to home, what will enhance even further the market size differences between home and foreign. Then, as a result of "cumulative causation" effects, the cycle of agglomeration can be repeated until all firms and mobile workers are located at home.

This cycle of agglomeration however can be broken when competition is very fierce, i.e.: for η, or t, or N very high or D very low. However, and maybe surprisingly, partial agglomeration at either home or foreign is still possible. This is shown in figure 6, which plots together figure 2 and figure 3. Conversely two stable spatial equilibriums arise when: u equals one and $0 < s < 1/2$, or u equals zero and $1/2 < s < 1$ (see proof in appendix). These equilibriums refer to spatial equilibrium C in equation 19.

To see that spatial equilibrium C is possible in the R&D model, note that:

$$\begin{aligned} \text{If } r &\rightarrow 1,\ \Delta\Pi = 0 \text{ for } s \rightarrow \tfrac{1}{2} + \tfrac{(1-\eta)(2D-t)}{2tN} \\ \text{If } r &\rightarrow 0,\ \Delta\Pi = 0 \text{ for } s \rightarrow \tfrac{1}{2} - \tfrac{(1-\eta)(2D-t)}{2tN} \end{aligned} \qquad (20)$$

If additionally η tends to one, or D is sufficiently small, or t or N are sufficiently large, then, it is possible that $(1-\eta)(2D-t)/2tN \in]0,1/2[$,

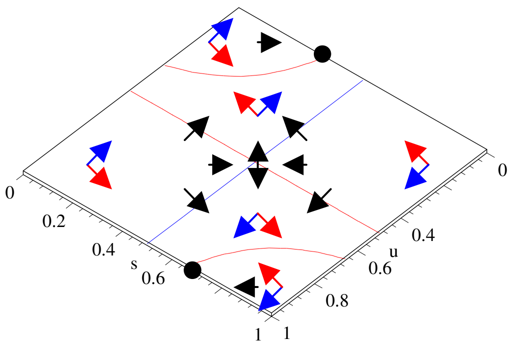

Figure 6: Spatial equilibrium: high competition levels

i.e.: there may exist an s (with $s \neq 0$, $s \neq 1$ and $s \neq 1/2$) where firms have no incentives to move given that $\Delta\Pi = 0$[20]. In the end, if these conditions are in place (i.e.: η close to one, or D sufficiently small, or t or N sufficiently large) the crossing of the spatial behavior of firms with that of workers can give rise to a stable asymmetric spatial equilibrium like C.

Proposition 6 *In an international oligopolist market, a spatial equilibrium arises with either total agglomeration or, when competition is very fierce with partial agglomeration.*

Compared to the NEG, this paper then differs in two ways: first it predicts a spatial equilibrium not present in the NEG literature: asymmetric dispersion; second it does not encompass the symmetric dispersed equilibrium[21]. This shows that the incentives for agglomeration are very strong in the R&D model, or so to say, R&D has a bias for agglomeration. Even when agglomeration is not total, it can be partial. This is an interesting result given that starting with "mirror" countries and firms in terms of preferences

[20]For $\eta > 1$ the following spatial patterns are obtained. For $1 < \eta \leq 2$ and $\eta > N + 1$ there is no stable spatial equilibrium. Instead, for $2 < \eta < N + 1$ the agglomerated equilibrium emerges alone (i.e.: $s = u = 1$ and $s = u = 0$). Then, for $\eta > 1$ the model behaves in a strange way. This confirms once again the choice of the parameter space where the game is valid.

[21]NEG models usually predict three types of stable spatial configurations: agglomeration only; agglomeration plus symmetric dispersion; and symmetric dispersion only.

and technology, differences in spatial demand patterns can trigger asymmetries at both levels: firms from some countries can become more competitive and as a result these countries attract more industry.

There are two main reasons for these dissimilarities. First, different demand structures are assumed here (quadratic) and in the NEG (Dixit and Stiglitz, 1977). With Dixit-Stiglitz preferences the scale of every firm, and therefore its labor requirement, is fixed by preferences and technology parameters. Consequently, migration of workers reduces the number of viable firms in the source country and raises the number of viable firms in the host country by exactly the same amount. With quadratic preferences, the scale of the firm is variable and so the rigid link between labor demands and firms number is broken. This happens independently of partial or general equilibrium. Second, the introduction of R&D expands the strategic space of firms what allows symmetry to be broken and asymmetry to be endogenized. As a result this also makes it possible to support spatial asymmetric outcomes, i.e.: dispersion without symmetry.

9 Discussion

This paper has studied the relation between the geography of innovation and the location of economic activity. It was found that R&D competition has an important spatial dimension. In fact, firms located in a country with more demand tend to be more competitive since they are able to invest more in R&D, i.e.: geography can make firms endogenously asymmetric. This "R&D linkage" between demand and efficiency encourages firms to strategically delocalize to the larger country to gain competitiveness, which can lead to "cumulative causation" effects that spur agglomeration of industry.

Actually, it was showed that R&D has a very strong tendency for agglomeration once, contrary to NEG models, it is not possible for the symmetric dispersed equilibrium to arise here. The only spatial equilibriums contemplated are either total or partial agglomeration (with one country hosting more firms than the other). The rational for this bias for concentration comes from the desire of firms to be more competitive than rivals, which is only possible by locating in the larger country. Furthermore, even in the presence of fierce competitive environments (that in the NEG promote symmetric dispersion) agglomeration is not totally broken: partial agglomeration is still possible. The possibility of this asymmetric dispersed spatial equilibrium is new in the literature and is particularly extraordinary given the symmetry assumptions at the base of the model adopted. Conversely, enlarging the space of firms' strategies can conduce to more real-world spatial patterns where "black-hole" or "mirror" locations are rare.

Results in this paper, then, give some clues for future research. First, some of the previsions of the R&D model deserve to be tested empirically given its novelty. Namely, the following must be investigated. Do firms from larger countries invest more in R&D? Do firms prefer to locate in regions where a higher level of R&D investment is performed? To answer these questions can be especially appealing, because the spatial innovation literature has so far ignored local endogenous innovation forces to focus mainly on geographically mediated knowledge spillovers (see Feldman, 1999). Second, the research conducted in this paper can be expanded to study other channels, besides demand, that can promote international asymmetries in innovation. To unveil some of these mechanisms may help to grasp some of the international location competition dynamics and explain the extremely uneven distribution of R&D activities in the world economy.

10 Appendix

Outputs and R&D The solution of the first-order conditions (FOCs) of profits in relation to outputs is:

$$\begin{aligned} bq &= \tfrac{D+(1-s)Nt+((1-s)N+1)\theta k-(1-s)N\theta k^*}{N+1} \\ bx &= \tfrac{D-((1-s)N+1)t+((1-s)N+1)\theta k-(1-s)N\theta k^*}{N+1} \\ bq^* &= \tfrac{D+sNt+(sN+1)\theta k^*-sN\theta k}{N+1} \\ bx^* &= \tfrac{D-(sN+1)t+(sN+1)\theta k^*-sN\theta k}{N+1} \end{aligned} \quad \text{(A1)}$$

In turn the solution of the FOCs for R&D investment is:

$$\begin{aligned} \gamma k &= \theta M\left(rq+(1-r)\,x\right) \\ \gamma k^* &= \theta M\left((1-r)\,q^*+rx^*\right) \end{aligned} \quad \text{(A2)}$$

To see this take the example of the R&D maximization problem for a representative home firm:

$$\begin{aligned} Max_k\,\Pi &= (P-C)\,qrM + (P^*-C-t)\,x\,(1-r)\,M - \Gamma \\ s.r. &: \quad C = c-\theta k \geq 0 \text{ and } k \geq 0 \end{aligned} \tag{A3}$$

This can be solved using the Kuhn-Tucker method. Start by writing the Lagrangian function (denoting the Lagrange multiplier by λ):

$$L = \Pi + \lambda\,(c-\theta k) \tag{A4}$$

Since it is considered that outputs and R&D levels are chosen simultaneously, the Kuhn-Tucker conditions are equal to:

$$\begin{aligned} \tfrac{\partial L}{\partial k} &= \theta M\,(rq + (1-r)\,x) - \gamma k - \lambda\theta \leq 0, \qquad k \geq 0, \qquad \text{and} \qquad k\tfrac{\partial L}{\partial k} = 0 \\ \tfrac{\partial L}{\partial \lambda} &= c - \theta k \geq 0, \qquad \lambda \geq 0, \qquad \text{and} \qquad \lambda\tfrac{\partial L}{\partial \lambda} = 0 \end{aligned} \tag{A5}$$

The non-negativity and the complementary-slackness conditions on λ (respectively $\lambda \geq 0$ and $\lambda\,(\partial L/\partial\lambda) = 0$) imply that if $\lambda = 0$, $k < c/\theta$; while for $\lambda > 0$, $k = c/\theta$ (since $\theta > 0$). Then, if $\lambda > 0$ and $k = c/\theta$, the complementary-slackness condition on k is never satisfied, since $k\,(\partial L/\partial k) \neq 0$ (i.e.: there is no corner solution). On the contrary, if $\lambda = 0$, $k < c/\theta$ and $k = \frac{\theta M}{\gamma}\,(rq + (1-r)\,x)$, the complementary-slackness condition on k is satisfied (since $k\,(\partial L/\partial k) = 0$) and consequently the same happens for the remaining Kuhn-Tucker conditions.

Sign of $\Delta\Pi$ The sign of the first term in the nominator depends only in $(r-1/2)$, since the remaining elements are positive if $D > t$ and $0 < \eta < 1$.

In turn, the sign of the second term in the nominator is the opposite of $(s-1/2)$, i.e.: the term inside square brackets is negative. To see this note first that the second term inside the square brackets is always negative. In what concerns the first term, this is comprehended between $]-1,0[$, i.e.: it is also negative. To confirm this check first that:

$$\begin{aligned} \eta &\to 1;\, \left(4\eta r\,(1-r)\left(1+\tfrac{1-\eta}{N+1}\right)-1\right) \to (4r\,(1-r)-1)\,, \text{ i.e.: } \to\,]-1,0[\\ \eta &\to 0;\, \left(4\eta r\,(1-r)\left(1+\tfrac{1-\eta}{N+1}\right)-1\right) \to -1 \end{aligned} \tag{A6}$$

For middle cases of η $(0 < \eta < 1)$ we can still use the fact that the sign of the expression depends also on r. Specifically:

$$
\begin{aligned}
r &\to 1;\ \left(4\eta r\left(1-r\right)\left(1+\tfrac{1-\eta}{N+1}\right)-1\right)\to -1 \\
r &\to 0;\ \left(4\eta r\left(1-r\right)\left(1+\tfrac{1-\eta}{N+1}\right)-1\right)\to -1
\end{aligned}
\tag{A7}
$$

For interior values of r $(0<\eta<1)$, note that the maximum of the expression is attained at $r=1/2$ where it simplifies to:

$$
\left(4\eta r\left(1-r\right)\left(1+\tfrac{1-\eta}{N+1}\right)-1\right)_{r=1/2}=\tfrac{(1-\eta)(\eta-(N+1))}{N+1}<0 \tag{A8}
$$

This all proves that the first expression in the square brackets of equation 17 in the main text is always negative and in consequence so it is the whole expression under square brackets. Further, the second term in the nominator has an inverted U-shaped form in relation to r with negative extremes close to $r=1$ and $r=0$.

Sign of $\Delta\Pi$ under Case 1: $r>1/2$ **and** $s>1/2 \Rightarrow$ ***(i)*** $\Delta\Pi>0$ **or** ***(ii)*** $\Delta\Pi<0$ If s and r are close to one, the second term in the nominator reaches its negative peak, and therefore it is under this case that most likely this term is bigger than the first, specially if also: η is close to one, or N or t are sufficiently big or D is sufficiently small. If η is close to one, the first term in the nominator and also the first term inside the square brackets almost vanish, and as such the nominator becomes negative, i.e.: $\Delta\Pi<0$. If D is sufficiently small, the second term supplants the first and therefore $\Delta\Pi<0$. If t is sufficiently big, the first term becomes smaller than the second, and $\Delta\Pi<0$. Finally if N is sufficiently large, the second term increases and can surpass the first one so that $\Delta\Pi<0$.

The contrary happens (i.e.: $\Delta\Pi>0$) for η, t, N not too big and D not too small, even if s and r are close to one.

Sign of the Indirect Utility Function To see that the nominator of equation 18 is always positive, note that the term inside squared brackets is comprehended between $]-1,1[$. Then, since $D>t$ the proof follows.

Stability Analysis Total agglomerated equilibriums (i.e.: spatial equilibriums B) are always stable given that: at $s=u=1$, $\Delta\Pi>0$ and $\Delta V>0$; and at $s=u=0$, $\Delta\Pi<0$ and $\Delta V<0$. In turn, spatial equilibriums C (i.e.: partial agglomerated equilibriums) are always stable for mobile workers, since at $u = 1$, $\Delta V > 0$; and at $u = 0$, $\Delta V < 0$. However, that is only so for firms if the slope of $\Delta\Pi$ (at $u = 1$ or $u = 0$) is non-positive. Similarly, spatial equilibriums D are always stable for firms once: at $s = 1$, $\Delta\Pi > 0$; and at $s = 0$, $\Delta\Pi < 0$. Though, that is only so for mobile workers if the slope of ΔV (at $s = 1$ or $s = 0$) is non-positive. For spatial equilibrium A the stability analysis requires the study of the Jacobian of the system evaluated at the equilibrium in question.

As shown in the text, however, in the R&D model only spatial equilibriums A, B, and C arise. Given what was said above, then, it is only necessary to check for the stability of spatial equilibriums A and C.

Proof that Spatial Equilibrium A is Saddle-Path Stable The Jacobian at $s = u = 1/2$ (i.e.: $J_{s=u=1/2}$) equals:

$$\begin{bmatrix} \frac{d\Delta\Pi}{ds} & \frac{d\Delta\Pi}{du} \\ \frac{d\Delta V}{ds} & \frac{d\Delta V}{du} \end{bmatrix}_{s=u=\frac{1}{2}} = \begin{bmatrix} -2NM\frac{t^2}{N+1} & LMt\frac{(2-\eta)(2D-t)}{(N+1-\eta)(1-\eta)M} \\ \frac{(2D-t)tN^2}{b(N+1-\eta)(N+1)} & 0 \end{bmatrix}_{s=u=\frac{1}{2}} \tag{A9}$$

As such the determinant of the Jacobian is negative and equal to:

$$\left| J_{s=u=\frac{1}{2}} \right| = -\frac{t^2N^2L(2D-t)^2(2-\eta)}{b(N+1-\eta)^2(N+1)(1-\eta)} < 0 \tag{A10}$$

Then, the spatial equilibrium $s = u = 1/2$ is saddle-path stable.

Proof that Spatial Equilibrium C is Stable Note that if $u = 1$ or $u = 0$, the first part of the nominator in equation 17 becomes a constant, i.e.: the term under square brackets is the slope of $\Delta\Pi$ at $u = 1$ or $u = 0$. Since this term is negative, implying a non-positive slope, then, spatial equilibrium C is stable.

Parameter Values Figures 1 and 2 Figures 1 and 2 can for instance be constructed with the following parameter values. Figure 1: $N = 100$, $t = 2$, $D = 5000$ and $\eta = 5/6$ (for example $M = 100$, $b = 1$, $\gamma = 3000$, $\theta = 5$). Figure 2 by substituting the above values to: $N = 1500$, or $t = 30$, or $D = 300$ or $\eta = 500/503$ (for example $M = 100$, $b = 1$, $\gamma = 2515$, $\theta = 5$).

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