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Location of R&D activities by vertical multinationals over asymmetric countries

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Abstract: This paper deals with the location of *R&D* by vertical multinational firms. By taking the colocation of laboratories and productive plants as a benchmark, we can see that the spatial separation of both emerges under two conditions – high intensity of *R&D* spillovers and strong size asymmetry between countries. The latter condition is effective since it is related with a rising international inequality of wages. If the spatial separation of *R&D* and manufacturing takes place, headquarters services (namely *R&D* units) will be likely located in the smaller country. The converse pattern, where laboratories are place in the larger country, may arise if production is *high-tech* and the localized externalities of research activity are strong. Hence, this article confirms the main results of the literature on this topic but in the context of a different framework which allows us to tackle two usually disregarded topics: the transfer cost of technology; and the direct engagement of industrial workers in *R&D* spillovers. These aspects are dealt with by presupposing that, in addition to a "technological" externality among researchers, there is an "educational" externality exerted by researchers upon neighbouring industrial workers. When a country loses its laboratories, the inhabitants become intellectually "impoverished" and their labour starts to have a lesser efficiency.

J.E.L. Classification: F23; O32; R12.

Keywords: Location of *R&D*; Vertical Multinationals; Spillovers; Nash Equilibria in a Large Group of Agents.

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1. Introduction

The location of *R&D* units is a subject which is scarcely dealt with. The dominant perception in this field is that research laboratories tend to be collocated with productive plants, in particular when the productive activity is basically *high-tech*.

However, multinational firms often set up *high-tech* production and *R&D* in different countries. Two examples of this kind of spatial separation are Sweden (which has a lot of *R&D* activity and comparatively few *high-tech* production) and Ireland (where the opposite relation holds).

The location of *R&D* activities is a part of the overall spatial strategy of multinational firms. In particular, it is closely connected with the location of the so called *vertical multinationals* (as in HELPMAN, 1984), a situation with zero trade costs in spite of the fact that there are economies of scale in the productive activity. In this case, *R&D* activities (and other headquarters services) may show either of two spatial patterns. [3]

They may either collocate with the plant if trade alone equalizes the prices of productive factors across countries. Or they may separate spatially from manufacturing through locating in a different country. The latter possibility arises if the relative factor endowments of the two countries are so opposed that trade is *per se* unable to equalize the factor costs across countries. In this situation, the firm locates each stage (*R&D*, manufacturing) in the country which is relatively abundant in the kind of input that this stage uses more intensively.

The forecasts of the vertical multinational firm are rather limited. All in all it amounts to say that *R&D* tends to locate in the country where human capital is available in larger quantities, the distribution of this input across countries being presupposed rather than explained by the model. Models where growth is led by the production of "blueprints" of differentiated consumer goods, such as MARTIN and OTTAVIANO (1999), are based on a given and fixed initial distribution of researchers across countries, although the manufacturing of each brand is not necessarily tied to the country where the product "idea" was initially conceived.

By assuming that trade costs are positive (although not "prohibitive"), the literature on the so called *horizontal* FDI (MARKUSEN and VENABLES, 2000; MARKUSEN, 2002) provides a likely forecast for the location of *R&D* units (and other headquarters services, in general), in the particular case where the two countries have approximate **relative** factor endowments, but very different **absolute** endowments or market sizes. In this case, the productive activity is driven by the interplay of positive trade costs and scale economies (the so called *Home Market effect*, as in KRUGMAN, 1980) and it concentrates in the country with the larger number of consumers. The agglomeration of plants in in the larger market raises factor costs there and it "crowds out" *R&D* activities to the smaller country which thus becomes the home for the headquarters of most multinational firms.

[3] DEFEVER (2006) remarks that, while *R&D* units are spatially driven towards high-tech production, the same kind of spatial orientation does not hold for other headquarters services.

Although some small countries, such as Sweden, the Netherlands and Switzerland, contain a disproportionately high share of multinational firm headquarters, there exist many instances of international corporation *R&D* services which are in large countries. In order to account for this possibility, the theory should include the positive technological externalities which each researcher exerts on his fellows who live and work close by (see SIEDSCHLAG et Al, 2013).

Hence, we can check empirically that the location of an *R&D* unit is driven by the knowledge base of the region where it is to be sited, as expressed by the intensity of patents. Evidence also clearly shows us that the proximity to centres of excellence in research is a very important factor when the firm chooses where to locate its new research facility abroad. Consequently, *R&D* units are placed where they can obtain technology from local sources.

By presupposing that *R&D* spillovers are strong enough, EKHOLM and HAKKALA (2007) account for the possibility that headquarters/labs within the multinational firm are placed in the larger country. Nevertheless their analysis suffers from two kinds of limitations. Firstly, there is no cost of technology transfer, i.e., the spatial separation of labs and factories does not entail any specific kind of expense. Secondly, technological externalities engage only labs thus leaving aside plants and the productive activity.

In this article, we confirm the main findings of the literature on *R&D* activity location and we deal with the two mentioned limits of previous analyses.

2. An overview of the economy

We presuppose an economy with two vertically related industries. The upstream industry is made up by a set of laboratories. Like in ROMER (1990), each laboratory produces a piece of non-rival technological capital, i.e., a differentiated "design" or "blueprint" of a producing process. The downstream industry is composed by manufacturing firms which combine these differentiated "blueprints" with labor so as to produce a consumer composite good.

As a preliminary approach, we presuppose a closed country, where N individuals live. Within the set of N persons, a number X are "researchers" who work in laboratories (*labs* henceforth) and Z are industrial workers operating in factories which produce a final composite good. Hence, we have

$$N = X + Z \tag{2.1}$$

As it was stated before, the economy is formed by two vertically linked industries:

1) An upstream industry is made by a set of identical *labs*. Each *lab* uses a physical unit of labor (an individual who is a "researcher") as a private input. However, following here the endogenous growth literature (FRANKEL, 1962; ROMER, 1986, 1990), the labor productivity of each "researcher" is determined, as a collective input, by the number X of *labs*/researchers which operate in the economy. This collective input is a source of externalities at two different levels:

- At the generation of "blueprints" of producing methods, i. e., at the production of the technological capital itself as expressed by K.
- As a local educative externality, similar to those present in LUCAS (1988) and BENABOU (1993). The proportion of researchers in total population enhances the average amount of human capital possessed by each individual working in the economy, including both researchers in *labs* and workers in factories. Hence, if we presuppose that the physical unit of labor is the unit (one employed person), the amount of labor in efficiency units that each individual supplies to production is labeled as $l \geq 1$.

We may summarize the description above by saying that the production function of a *lab* is given by,

$$K = Xl \tag{2.2}$$

From (2.2), we see that the output of a *lab* is positively influenced by the collective input of research work in the overall economy and by the labor efficiency of the researcher who works for that *lab*.

In turn, the labor efficiency of workers (both researchers and industrial workers) is an increasing function of the proportion of researchers in the country's labor force. Not only a researcher produces technological knowledge, but in addition he disseminates knowledge in the labor force, thus increasing the labor productivity in the overall economy. We model this educational externality as,

$$l = \min\left\{1 + \frac{X}{N}, 1 + \alpha\right\} \tag{2.3}$$

In (2.3), as it will be seen ahead, α stands for the elasticity of technological capital in the overall production function, or, what is equivalent, it represents the share of this kind of capital in total production costs. This informal education function is plotted in Figure 1.

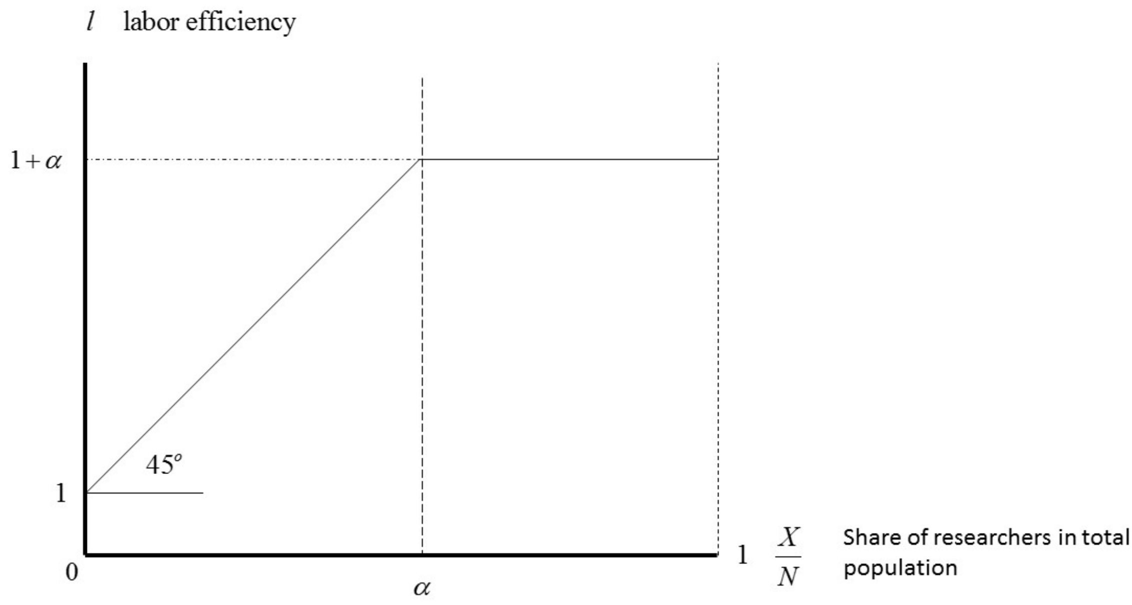

Figure 1: Determinants of labor efficiency

The degree of knowledge and skills of agents varies directly with the proportion of researchers in total population and with the relative importance, α, of technological capital as an input to production of the consumer composite good.

2) A manufacturing firm which combines technological capital (a "blueprint" of a productive process) with labor in order to produce a consumer composite good. Since both upstream *labs* and downstream manufacturing firms form perfectly competitive firms, we may assume that the prices of both a "blueprint" and the final composite good are given to the individual firms and equal to 1 without loss of generality.
   Consequently, this economy may also be regarded as being made by competitive, vertically integrated firms. Each vertically integrated firm uses one researcher and z industrial workers according to the production firm

$$y = K^{\alpha}\left(zl\right)^{(1-\alpha)} \tag{2.4}$$

   Or, by substituting (2.2) in (2.4), we have

$$y = \left(Xl\right)^{\alpha}\left(z\,l\right)^{(1-\alpha)} \tag{2.5}$$

   where y stands for the output of composite good generated by a vertically integrated firm and $\alpha \in (0,1)$ is a distribution parameter.

Parameter $\alpha \in (0,1)$ has a triple economic meaning:

1. According to (2.4), it gives the *technological intensity* of the industry. A high α expresses the fact that the industry is a *high-tech* one.
2. Bearing in mind that, (2.5) can be written as

$$y = X^{\alpha} z^{(1-\alpha)} l \tag{2.6}$$

   α can be seen to express the intensity of spillovers across researchers or labs.

3. By taking function (2.3) in Figure 1 into consideration, α can be regarded as bounding from above the positive external influence that research activities in a country exert upon the efficiency of their workers, thus upon the overall educational level in that country.

We begin to determine the profit-maximizing number of workers hired by the representative firm, thus determining its size.

We assume that the vertically integrated competitive firms behave as a "large group" of symmetric agents (as in CHAMBERLIN, 1948), where each one presupposes that, when it varies the amount of labor engaged, the other firms keep their volumes of industrial employment unchanged. Consequently, each firm takes as given the total number Z of industrial workers and the associated variables, namely $X = N - Z$, the number of researchers and $l = \min\left\{1+\frac{X}{N}, 1+\alpha\right\}$, the efficiency of each agent (either worker or researcher) in the economy.

Like in ROMER (1990), technological capital works as joint, non-rival input to many industrial firms. Consequently, each vertically integrated firm faces the expenditure with the technological capital that it uses as a fixed cost, F, so that the aggregate profit function of the consumer good industry becomes from (2.5)

$$\pi(z) = \left[(Xl)^{\alpha}(zl)^{(1-\alpha)}\right] - wz - F \tag{2.7}$$

The representative firm maximizes its profit in relation to the amount of labor used, z. An interior maximum is reached by solving the first order condition, as

$$\pi'(z) = (Xl)^{\alpha}(1-\alpha) z^{(-\alpha)} l^{(1-\alpha)} - w = 0 \tag{2.8}$$

Or, solving for the wage

$$\hat{w} = X^{\alpha}(1-\alpha) z^{(-\alpha)} l \tag{2.9}$$

The profit maximizing level of hired labor fulfills the condition (2.8) that in a competitive industry the wage should equal the value of the marginal product of labor.[4]

Substituting $\hat{w}$ from (2.9) into the profit function (2.7) and equating this function to zero, since the vertically integrated firm is perfectly competitive, we obtain the condition,

$$\pi = \left[(XL)^{\alpha} (zl)^{(1-\alpha)} \right] - \left[X^{\alpha} (1-\alpha) z^{-\alpha} l \right] z - F = 0 \tag{2.10}$$

By solving (2.10), we obtain the equilibrium reward of technological capital, $\tilde{F}$

$$\tilde{F} = \alpha X^{\alpha} z^{(1-\alpha)} l \tag{2.11}$$

We presuppose now that the set of individuals in the economy play a symmetric static game, where each person decides to become either a "researcher" or an "industrial worker", taking as given the aggregate numbers of "industrial workers" and "researchers", Z and $X = N - Z$, respectively, in the economy.

A symmetric game usually has a symmetric Nash equilibrium, which is defined as an equilibrium where each player uses the **same** strategy (either pure or mixed). Henceforth, following the steps of CHAMBERLIN (1948), we will concentrate on symmetric equilibria only. In this case, if all participants select the same **pure** strategy, each one choosing to become either an "industrial" worker or a "researcher", a Nash equilibrium does not exist, since the production of the final good entails the combination of both stages, R&D and manufacturing, within the same vertically integrated firm.

Clearly, the unique symmetric Nash equilibrium of this large group game is the one where each player selects a completely mixed strategy, which, for given aggregate values of industrial workers and researchers, implies that both pure strategies give the same payoff. The following condition must be satisfied for a symmetric Nash equilibrium to exist.

$$\tilde{F} = \hat{w} \tag{2.12}$$

Plugging (2.9) and (2.11) into (2.12) and solving for the number of industrial workers in each firm, we get

$$\tilde{z} = \frac{1-\alpha}{\alpha} \tag{2.13}$$

[4] It can be easily checked in (2.7) that $\pi(z)$ is a strictly concave function.

The equilibrium value of z decreases with the degree of the technological intensity of the production of the final composite good, as shown by the parameter α.

3. The case of two asymmetrically sized countries

We now presuppose an economy made by two asymmetric countries, namely *North*, with population N and *South,* with N^* consumers/workers. *North* is the larger country so that the inequality $N > N^*$ always holds. Henceforth, it will be assumed that the asterisk * labels magnitudes concerned with the smaller country *South.*

Labor is immobile across countries, but the technological capital produced in a country may be used by a plant in the other country in the context of a vertical multinational firm.

We can prove the following proposition.

Proposition 1: If, in both countries, all firms are "national", in the sense that each firm employs locally a researcher and a set of z industrial workers, then the rewards of both technological capital and labor will be higher in the larger country *North*.

Proof: Indeed, from (2.11), the ratio between equilibrium values of the reward of technological capital $\tilde{F}$ in *North* and *South* is

$$\frac{\tilde{F}}{\tilde{F}^*} = \frac{\alpha X^{\alpha} z^{(1-\alpha)} l}{\alpha \left(X^*\right)^{\alpha} \left(z^*\right)^{(1-\alpha)} l^*} \tag{3.1}$$

From (2.13), we have $z = z^* = \dfrac{1-\alpha}{\alpha}$ and, consequently,

$$Z = Xz = X\frac{(1-\alpha)}{\alpha}$$

Since we have $Z = N - X$, the equation follows

$$N - X = X\frac{(1-\alpha)}{\alpha} \tag{3.2}$$

whose solution is

$$X = \alpha N \tag{3.3}$$

Similarly, for *South*, we have

$$X^* = \alpha N^* \tag{3.4}$$

Moreover, from (2.3) and Figure 1, we have that

$$l = l^* = 1 + \alpha \tag{3.5}$$

By inserting (3.3), (3.4) and (3.5) into (3.1), the latter expression becomes

$$\frac{\tilde{F}}{F} = \left(\frac{N}{N^*}\right)^{\alpha} > 1 \tag{3.6}$$

From (2.9), the ratio of equilibrium wages in *North* and *South* can be written as

$$\frac{\hat{w}}{\hat{w}^*} = \frac{X^{\alpha}(1-\alpha) z^{-\alpha} l}{\left(X^*\right)^{\alpha}(1-\alpha)\left(z^*\right)^{-\alpha} l^*} \tag{3.7}$$

Applying the same reasoning as before, we can conclude that, when all firms are national, equilibrium wages are higher in the larger country, i.e. it can be easily shown that

$$\frac{\hat{w}}{\hat{w}^*} = \left(\frac{N}{N^*}\right)^{\alpha} > 1 \tag{3.8}$$

QED

Similar in some way to models with positive transport costs and production under increasing returns (such as MARKUSEN and VENABLES, 1998 and 2000), where a *Home Market* arises in the location of productive units (as in KRUGMAN, 1980), factor prices also rise here in the larger country. However, as now the economy is perfectly competitive and it works under zero trade costs, the rise in factor prices in the northern country is exclusively due to externalities in R&D which are enhanced by country population size.

3.1. Equilibrium spatial distribution of production

We now deal with the location of the productive activities in this economy. As it was seen before, these are R&D and the manufacturing of a final consumer good across the two asymmetric countries.

As before, since the location decisions are taken simultaneously by a large group of symmetric firms, we will restrict our analysis to two symmetric Nash equilibria, namely

- The pattern where all firms are "national", research and manufacturing being performed in the same proportion within each country. We will name this pattern as the "national pattern".
- The pattern where all firms are "multinational" and country specialization is complete. All firms perform research in a country and combine the technological capital thus created with labor to manufacture a final consumer good in the other country.[5]

In what follows, we derive the necessary and sufficient conditions so that each type of locational symmetric Nash equilibrium holds.

3.2. Equilibrium without country specialization: the "national pattern"

We consider now situations where each firm is "national", in the sense that it performs both research and manufacturing in a single country. We have seen before that the symmetric Nash equilibrium of a large group of individuals entails the adoption of a completely mixed strategy whose support is the set of pure strategies (to become an industrial worker, to become a researcher). Given the aggregate numbers of both professions, Z and $X = N - Z$, the completely mixed equilibrium strategy is defined by the indifference condition (2.13), which we can write here considering now two asymmetric countries as

$$z = z^* = \frac{1-\alpha}{\alpha} \tag{3.9}$$

Let us consider the parameter space $\left(\alpha, \frac{N^*}{N}\right)$, where $\alpha \in (0,1), \frac{N^*}{N} \in (0,1)$ stand for the share of technological capital in total production costs and the coefficient of symmetry in size between countries *South* and *North.* Two remarks on this type of symmetric Nash equilibrium are suitable to say now.

Firstly, conditions (3.9) hold in any point of the above mentioned parameter space. Hence, a situation where production is undertaken by national, single plant firms is always feasible.

Secondly, since this Nash equilibrium entails a completely mixed strategy for each player it is **non-strict**, in the sense that each player has two pure best replies to any aggregate numbers

[5] The assumption of complete country specialization will be introduced here for the sake of simplicity.

of “workers” and “researchers”. Consequently, an arbitrarily small shift of parameter α can shift the economy to an out of equilibrium situation (see among others WEIBULL, 1997, p. 15).

Hence, this kind of equilibrium will be treated differently according to the specific position in parameter space $\left(\alpha, \frac{N^*}{N}\right)$. Where it is the **unique** Nash equilibrium, it will be taken as the solution of the game. Otherwise, whenever another strict Nash equilibrium, possibly involving a multinational organization of production, is present, the latter will be selected as the outcome of the game.

3.3. Equilibrium with full country specialization: the “multinational” pattern

We assume now that a symmetric arrangement holds where all firms are vertical multinationals. Hence, they perform research in a single country and use the technological capital thereby generated in order to manufacture a consumer good employing the individuals living in the other country. For simplicity, we presuppose that country specialization is full. A country only does R&D while only manufacturing takes place in the other country.

3.3.1. Multinationals have headquarters in the larger country

We start with the assumptions that all firms do research in the *North*, manufacturing being performed exclusively by industrial workers in *South*. Only laboratories locate in the *North* whose inhabitants are all researchers.

This pattern is an equilibrium if and only if the following two conditions are both satisfied:

- No researcher in the *North* finds profitable to become an industrial worker, i.e.

$$\tilde{F}_m \geq \hat{w}_m \tag{3.10}$$

where the subscript m indicates that we are dealing with a situation where firms are multinationals.

- No industrial worker in the *South* has an incentive to become a researcher. This is equivalent to assume that

$$\tilde{F}_m^* \leq \hat{w}_m^* \tag{3.11}$$

We can prove the following proposition.

Proposition 2: The condition $\tilde{F}_m^* \leq \hat{w}_m^*$ in (3.11) is trivially fulfilled.

Proof: The complete specialization of each country in a stage (*North* in *R&D*, *South* in manufacturing) determines the following equalities.

$$\begin{aligned}
&X = N \text{ and } X^* = 0 \\
&Z = 0 \text{ and } Z^* = N^* \\
&z^* = \frac{Z^*}{X} = \frac{N^*}{N} \\
&l = \min\left\{1+\frac{X}{N}, 1+\alpha\right\} = \min\{2, 1+\alpha\} = 1+\alpha \\
&l^* = \min\left\{1+\frac{X^*}{N^*}, 1+\alpha\right\} = \min\{1, 1+\alpha\} = 1
\end{aligned} \tag{3.12}$$

According to (2.9), the equilibrium wage paid by the multinational firm headed in *North* to the industrial workers in *South*, in the right hand side of inequality (3.10) is

$$\hat{w}_m^* = (Xl)^\alpha (1-\alpha) z^{*(-\alpha)} l^{*(1-\alpha)} \tag{3.13}$$

It follows from (3.12) that the wage $\hat{w}_m^*$ in (3.13)simplifies to

$$\hat{w}_m^* = N^{(2\alpha)} N^{*(-\alpha)} (1+\alpha)^\alpha (1-\alpha) \tag{3.14}$$

If an industrial worker in *South* switches to become a researcher, then he would set up a single-plant “national” plant. Consequently, his reward, $\tilde{F}_m^*$, could be expressed as the difference between the total revenues of a “national” firm located in *South* and total industrial labor costs at the wage rate which is paid in *South* by multinational firm subsidiaries, i.e.

$$\tilde{F}_m^* = \left[\left(X^* l^*\right)^\alpha \left(z^* l^*\right)^{(1-\alpha)} \right] - \left(z^* \hat{w}_m^*\right) \tag{3.15}$$

where variables take the following values.

$$X^* = 1$$
$$l^* = 1 + \frac{X^*}{N^*} \approx 1 \text{ for } N^* \text{ large} \tag{3.16}$$
$$z^* = \frac{Z^*}{N} = \frac{N^* - 1}{N} \approx \frac{N^*}{N} \text{ for } N^* \text{ large}$$

By inserting (3.16) and (3.14) into (3.15), the researcher's reward in *South* can be simplified as

$$\tilde{F}_m^* = \left(\frac{N^*}{N}\right)^{(1-\alpha)} \left[1 - N^\alpha (1+\alpha)^\alpha (1-\alpha)\right] \tag{3.17}$$

Taking into account (3.14) and (3.17), inequality $\tilde{F}_m^* \le \hat{w}_m^*$ becomes

$$\left(\frac{N^*}{N}\right)^{(1-\alpha)} \left[1 - N^\alpha (1+\alpha)^\alpha (1-\alpha)\right] \le N^{(2\alpha)} N^{*(-\alpha)} (1+\alpha)^\alpha (1-\alpha) \tag{3.18}$$

It is direct to show that inequality (3.18) simplifies as

$$\frac{N^*}{N}(1-K) \le K \text{ where } K \equiv N^\alpha (1+\alpha)^\alpha (1-\alpha) \tag{3.19}$$

It is clear that inequality is fulfilled for any values of N, N^* and α, because the values of K and N can be set to any desired value through the choice of adequate of units of measure of total population in a country. It is also self-evident that this choice does not change the ratio $\frac{N^*}{N}$. Specifically, if we set the units of population such that $K < 1$, then inequality (3.19) becomes

$$\frac{N^*}{N + N^*} \le K \tag{3.20}$$

Since $N^* < N$ implies that $\frac{N^*}{N + N^*} < \frac{1}{2}$, inequality (3.20) can be written as

$$\frac{N^*}{N + N^*} < \frac{1}{2} \le K \tag{3.21}$$

Then, if we set $\frac{1}{2} \le K < 1$, then inequality (3.20) will be always met. *QED*

Hence, the organization of industrial production within a vertical multinational where all researchers live in the large country *North* and all manufacturing workers have residences in the small country arises if and only if condition (3.10) is met, namely

$$\tilde{F}_m \geq \hat{w}_m$$

The reward paid by the multinational to its researcher in *North* is the difference between total revenues and total expenditure in wages paid to the workers living in *South*, i.e.

$$\tilde{F}_m = \left[(Xl)^{\alpha} \left(z^* l^* \right)^{(1-\alpha)} \right] - \left(z^* \hat{w}_m^* \right) \tag{3.22}$$

By plugging terms from (3.12) and (3.14) into (3.22), the fixed cost of technological capital for the multinational can be simplified as

$$\tilde{F}_m = \alpha (1+\alpha)^{\alpha} N^{(2\alpha-1)} N^{*(1-\alpha)} \tag{3.23}$$

By substituting (3.14) and (3.23) in (3.10), the condition of non-deviation by a researcher in *North* can be shown to mean that

$$\frac{N^*}{N} \geq \frac{1-\alpha}{\alpha} \tag{3.24}$$

As $1 > \frac{N^*}{N} \geq \frac{1-\alpha}{\alpha}$, a necessary condition for inequality (3.24) to hold is that

$$\alpha > \frac{1}{2} \tag{3.25}$$

This means that multinationals with headquarters in *North* can arise only if technological capital is important to raw labor as an input to the production of consumer goods, i.e., if the productive activity is a high-tech one.

3.3.2. Multinationals have headquarters in the smaller country

Since the two countries are symmetric in all aspects but in what concerns population size, the equilibrium condition of a pattern where firms are multinationals with headquarters in *South*, can be obtained from (3.24) by interchanging parameters N and N^*.

$$\frac{N}{N^*} \geq \frac{1-\alpha}{\alpha} \leftrightarrow \frac{N^*}{N} \leq \frac{\alpha}{1-\alpha} \tag{3.26}$$

We can also easily seen that the equivalent of **Proposition 2** for *South-based* multinationals always holds. Let us assume that a multinational with headquarters in the smaller country pays wage $\hat{w}_m$ to its workers in the plant located in *North.* If one of this workers unilaterally becomes a researcher, then he would get $\tilde{F}_m$ as reward for his research output. By symmetry with **Proposition 2**, we are able to write inequality $\tilde{F}_m \leq \hat{w}_m$, whose two sides can be easily written by interchanging parameters N and N^* in (3.14) and (3.17).

We should remember that a non-strict Nash equilibrium with only national firms exists for any parameter values. In Figure 1, we plot the $\left(\alpha, \frac{N^*}{N}\right)$ parameter space the conditions (3.24) and (3.26) that bound the regions where both types of multinational firms (either based in North, or in South) are in equilibrium.

4. Vertical multinational firms in the context of size asymmetry across countries – plot and discussion

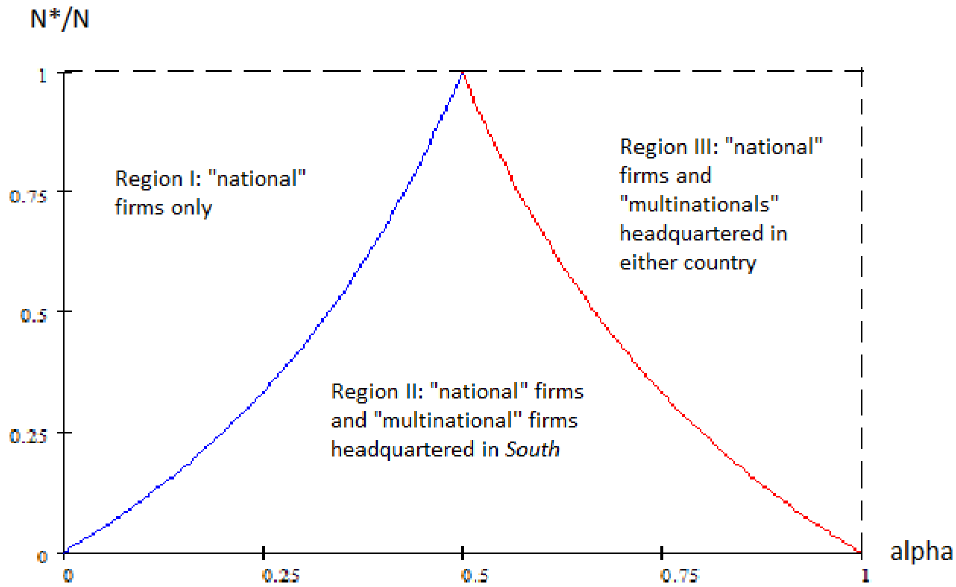

Figure 1: Spatial organization of production within vertical multinationals in parameter space (alpha, N*/N)

Figure 1 shows the spatial pattern of production for different regions of the parameter space $\left(\alpha, \frac{N^*}{N}\right)$. Since multiple equilibria do emerge in some regions, we should provide some qualifications on equilibrium selection.

As it was said clearly before, the equilibrium with "national firms only" is a **non-strict** Nash equilibrium where each player uses the same **completely mixed** strategy with support in the two pure strategies "to become a researcher" and "to become an industrial worker". By contrast, the Nash equilibria where only multinational firms exist, either based in *North* or in *South*, are **strict** Nash equilibria, since now each player adopts the same **pure** strategy within each country. Consequently, we will consider that an equilibrium with "national firms only", holds in the situation where it is the **unique** Nash equilibrium (that is to say, in region I in Figure 1) and in no other one.

Having settled this aspect, it remains to select one kind of multinational firm (either *North* or *South* based) in region III of Figure. We can easily prove a proposition which may help us for this purpose.

Proposition 3: The comparison of factor rewards by multinational firms with headquarters in different countries leads to the following results:

a) The northern based multinational pays higher wages to its manufacturing workers than the southern based one because it provides relatively more technological capital to its manufacturing plants.
b) When both types of multinational firms are feasible, the reward of technological capital by the southern based multinational will be higher (lower) than the one prevailing under the northern based counterpart if and only if $\frac{1}{2} < \alpha < \frac{2}{3}$ $\left(\frac{2}{3} < \alpha < 1\right)$, respectively.

Proof: a) The wage paid by a northern based multinational to its workers living in *South* is, from (3.14)

$$\hat{w}_m^* = N^{(2\alpha)} N^{*(-\alpha)} (1+\alpha)^{\alpha} (1-\alpha)$$

By interchanging parameters N and N^*, the wage paid by a southern based multinational to its workers with residence in *North* is

$$\hat{w}_m = N^{*(2\alpha)} N^{(-\alpha)} (1+\alpha)^{\alpha} (1-\alpha)$$

Taking the ratio of the two wages and simplifying, we obtain

$$\frac{\hat{w}_m^*}{\hat{w}_m} = \left(\frac{N}{N^*}\right)^{(3\alpha)} > 1 \tag{4.1}$$

b) The reward of technological capital by a multinational based in *North* is, from (3.23)

$$\tilde{F}_m = \alpha (1+\alpha)^{\alpha} N^{(2\alpha-1)} N^{*(1-\alpha)}$$

By symmetry, the reward of technological capital by a southern based multinational is

$$\tilde{F}_m^* = \alpha (1+\alpha)^{\alpha} N^{*(2\alpha-1)} N^{(1-\alpha)}$$

Taking the ratio of the two rewards and further simplifying, we obtain,

$$\frac{\tilde{F}_m^*}{\tilde{F}_m} = \left(\frac{N^*}{N}\right)^{(3\alpha-2)} \tag{4.2}$$

Consequently, we have the following inequalities,

$$\begin{aligned} &\text{If } \alpha < \frac{2}{3}, \text{ then } \tilde{F}_m^* > \tilde{F}_m \\ &\text{If } \frac{2}{3} < \alpha < 1, \text{ then } \tilde{F}_m^* < \tilde{F}_m \end{aligned} \tag{4.3}$$

QED.

Bearing in mind the conditions of Nash equilibrium selection, several comments on Figure 1 are in order.

Firstly, vertical multinational firms – irrespective of where they are headquartered - tend to arise for a moderate to high α value. The spatial separation of *R&D* units and productive plants is more likely to emerge in *high-tech* industries and whenever localized spillovers are important. This is the case of industries pharmaceuticals and telecommunications where this kind of spatial separation happens more usually.

Secondly, vertical multinationals and the split of *R&D* and manufacturing tend to emerge if the two countries are very asymmetric in size. This happens because size asymmetry enhances the inequality of factor prices across countries (see above **Proposition 1**), the larger country exhibiting higher prices for both technological capital and labor. As in HELPMAN (1984) and MARKUSEN and VENABLES (2000), this creates an incentive for separating R&D and manufacturing across countries.

Thirdly, the model shows a strong bias for the empirical fact that many multinationals set up headquarters and research labs in small countries. In this article, multinationals tend to locate headquarters in the smaller country if the asymmetry between *South* and *North* is high and if the relative importance of technology in production is medium sized. The latter condition is intuitive. If α is very low, there is no incentive to split headquarters and manufacturing plant and the firm works as a “national” firm. If α is very high, the sheer importance of R&D in overall production leads the firm to specialize the population of the larger country *North* in its performance.

The former condition is still more interesting since it confirms the literature on multinational firm location. As MARKUSEN and VENABLES say:

> *This may help us to understand the importance of smaller countries such as Sweden, Switzerland and the Netherlands as home countries for multinationals. Essentially, production is drawn into the larger country, leaving the smaller country with a comparative advantage in headquarter service production. (MARKUSEN and VENABLES, 2000: 228)*

Although there is no *Home Market* effect in this paper, since trade costs on the final output are zero and the economy operates under perfect competition, R&D tends to concentrate in the smaller country because this pattern leads to lower labor costs.

The opposing case where *R&D* concentrates in the larger country drives here from the same determinants as in EKHOLM and HAKKALA (2007), namely from a high value for parameter α. If production is very high-*tech* and spillovers across labs are crucial, then for the firms it pays off to collaborate with a large *R&D* sector. This can be achieved by specializing the inhabitants of *North* in *R&D*.

Our analysis integrates two aspects which were formally ignored beforehand and whose inclusion makes the approach more realistic. Departing from a situation where R&D and production take place in both countries in "national firms", the formation of multinational firms leads to a negative "educational" externality in the country which specializes in manufacturing. The fact that this country loses the labs which used to operate aside plants causes an "educational impoverishment" which shows itself in a fall of labor efficiency of workers.

By adding this "educational" externality we are able to tackle two different aspects of the analysis which were previously ignored. The spatial separation of *R&D* and plant brings about a cost in labor efficiency which is borne by the country which loses its research capacity. Furthermore, *R&D* spillovers are not confined to researchers but they also engage plants and industrial workers.

5. Concluding remarks

By taking the colocation of *R&D* units and plants within national firms as the benchmark, we were able to see that a spatial separation by multinationals arises under two conditions. Firstly, the intensity of production in *R&D* and its geographically localized spillovers should be high enough to make a country specialization in laboratory activity profitable. Secondly, the two countries should be sufficiently asymmetric in size so that an international difference in factor costs emerges, thereby creating an incentive to separate activities in space and assign each stage to the country where the most used input is available in relatively larger quantity.

It is likely that the newly formed vertical multinational firms will place *R&D* units (alongside with other headquarters services) in the smaller country, where factor costs are lower. The opposite location strategy, labs being located in the larger country, will more likely prevail if the production is very intensive in *R&D* and the technological externalities brought about by researchers in their neighborhood are high enough.

This analysis takes in consideration two aspects which were previously neglected. The spatial separation of labs and factories yields a positive technology transfer cost. Moreover, *R&D* spillovers do not engage only researchers but also affect the productive activity. Both aspects are tackled in this article by presupposing that when a country loses its *R&D* units by specializing in manufacturing, the average efficiency of its labor force is diminished in the context of a negative "educational" externality.

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