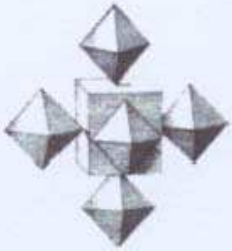

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by

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2011

Working Paper Series: IL. 52/11

Departamento de Fundamentos del Análisis Económico I

Ekonomi Analisiaren Oinarriak I Saila

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Relocation and Investment in R&D by Firms

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Abstract

The literature on foreign direct investment has analyzed firms' location decisions when they invest in R&D to reduce production costs. Such firms may set up new plants in other developed countries while maintaining their domestic plants. In contrast, here we consider firms that close down their domestic operations and relocate to countries where wage costs are lower. Thus, we assume that firms may reduce their production costs by investing in R&D and also by moving their plants abroad. We show that these two mechanisms are complementary. When a firm relocates it invests more in R&D than when it does not change its location and, therefore, its production cost is lower in the first case. As a result, investment in R&D encourages firms to relocate. When firms do not invest in R&D on relocation, R&D discourages firms to relocate since the investment made by the firms that remain in the country partially offsets the labor cost advantage obtained by the firms that move their plants abroad.

JEL classification: D6; F16; J51; L13.

Keywords: Relocation; R&D; Trade unions, Social welfare, Imperfect competition.

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Introduction

The relocation of firms, which affects market structure in advanced countries, is a matter of current interest given the liberalization currently under way in world trade. The literature studying the location decisions of firms has mainly analyzed the different factors that influence such decisions, e.g. reducing wage costs, entering foreign markets and establishing cooperation agreements between firms, and how governments can influence them (see, e.g. Mucchielli and Saucier, 1997; Feenstra, 1999; Blomstöm and Kokko, 2003; Fumagalli 2003; Bárcena-Ruiz and Garzón, 2003). These studies have been extended to analyze whether the relocation of firms is harmful to the countries out of which they move because of the resulting loss of employment when the labor force is unionized (see, e. g. Leahy and Montagna, 2000; Lommerud et al., 2003; Bárcena-Ruiz and Garzón, 2009). However, these papers do not take into account that when firms move to new locations abroad, their established knowledge may need to be adapted to the circumstances prevailing there, and this may justify some investment in R&D (European Commission, 2010).

Empirical evidence shows that R&D investment is an important factor that affects firms' locations (see European Commission, 2010). However, papers analyzing R&D competition and the importance of the transfer of technological knowledge between firms usually consider oligopolistic firms producing within a single country and, therefore, ignore firms' location decisions.[1] Petit and Sanna-Randaccio (2000) extend the above studies by considering a two-developed-country model with one firm located in each country, in which the firms can expand abroad by exporting or by building a new plant in the foreign developed country (foreign direct investment, FDI). They show that investment in R&D encourages the firms to expand abroad via FDI rather than via exports.[2] Norbäck (2001) analyzes the same issue but considers a single firm that produces a good whose demand is located in another country. The firm decides its technology, which can be implemented at home without cost or abroad with a transfer cost (since it must be adapted to

[1] See, e. g. d'Aspremont and Jacquemin (1988), Kamien *et al.* (1992) and Petit and Tolwinski (1998).

[2] Gerbasch and Schmutzler (2011) jointly analyze the foreign entry decisions and R&D location decisions made by two firms based in different countries. They show that liberalization of FDI may cause a relocation of R&D activities.

local conditions). He shows that if technology transfer costs are low (high), R&D intensive firms decide to use this technology in an affiliate (domestic plant) which supplies the market from a foreign plant (by exporting its production).[3]

Although there are various factors that lead firms to change the location of their production plants, this paper focuses on relocations that seek to reduce labor costs (in order to be competitive in the home market) since there is currently more and more empirical evidence that shows that firms are deciding to move to countries where wage costs are lower.[4] In advanced countries, the labor market is characterized by high levels of unionization, whereas in less advanced countries there is little or no trade union presence or wage bargaining, so labor costs are lower.[5] The objective of this paper is to analyze firms' decisions as to whether to relocate to a country with lower labor costs when they invest at the same time in R&D to reduce the marginal cost of production. Thus, we consider two ways of reducing production costs: by investing in R&D and by relocating the firm.

Our paper differs from that of Petit and Sanna-Randaccio (2000) and Norbäck (2001) in several points. First, their papers do not analyze whether R&D encourages FDI; they compare FDI and exports assuming that firms always invest in R&D. In contrast, we analyze whether R&D encourages relocation by comparing the case in which firms invest in R&D with that in which firms do not do so. Second, their papers focus their analysis on the study of how firms can enter new markets, while we study how firms can be competitive in their home markets. Finally, we consider two ways of reducing marginal production cost: the

[3] There are other related papers that focus only on one of these two factors: location decisions (Siotis, 1999; Bjorvatn and Eckel, 2006) or R&D decisions (Belderbos *et al.*, 2008).

[4] For example, the European textile sector is closing factories in Europe to relocate to countries with lower wages due to the total liberalization of textile trade that took place in 2005. Similarly, in the automotive industry, some firms are relocating their production plants to the Eastern Europe, Brazil or China, where the labor costs are lower [El País, 29/9/2004].

[5] The literature on wage bargaining has analyzed how the structure in which workers are organized to bargain wages affects R&D investment by firms that increases the productivity of labor (see, e.g. Tauman and Weiss, 1987; Ulph and Ulph, 1998; Calabuig and González-Maestre, 2002; Bárcena-Ruiz and Campo, 2009). However, these papers do not analyze firms' decisions as to whether to relocate to countries where wage costs are lower.

marginal cost of labor can be reduced by relocating the firm and the marginal cost of capital can be reduced by investing in R&D; in contrast, they consider only the second mechanism.

An example than illustrates the problem analyzed in the paper is given by the Renault–Nissan Alliance, signed on March 1999. Many automobile manufacturers are relocating their productive plants to countries with lower labor costs to guarantee their survival. In this regard, Renault decided to close its plant at Vilvoorde (Belgium) in 1997. In March 2007 the alliance decided to build an automobile manufacturing plant in southern India. India is now not only the production hub for compact cars for Japanese auto giant Nissan Motor Company: it is also going to be the company's R&D hub.[6] Another example is given by the Finnish firm Nokia, which opened its first plant in Beijing (China) in 1985. By the turn of the century China was Nokia's main production center worldwide. Nokia has opened two world-wide R&D centers in China, has many offices in different regions of the country, and has moved there the production process for all of its products there (see www.nokia.com/press).[7]

In order to analyze the issue proposed in the paper, we consider an advanced economy made up of two firms that produce a homogeneous good by using labor and capital as production factors. All workers are unionized and there is an independent union at each firm. In order to determine the wage set at each firm, we consider the monopoly-union model (see Booth, 1995) in which the wage is set by the unions and firms then choose the employment level. The marginal production cost comprises the marginal cost of capital and the marginal cost of labor (the wage). We assume that the marginal cost of capital can be reduced by investing in R&D and that the marginal cost of labor can be reduced by relocating the firm to a country with non-unionized workers.[8] When a firm relocates it

[6] See www.thehindubusinessline.com/2010/01/19/stories/2010011951230200.htm and www.renault.com.

[7] Similarly, Microsoft entered the Chinese market in 1992 and since then has invested a great deal of money to build its R&D Center, the Investment Institute in Asia and the World-wide Technology Centre. Microsoft moved production of its Xbox to China and now produces computer mouses in Guangdong (see www.microsoft.com/presspass).

[8] It could be assumed that each firm invests in R&D which increases the marginal productivity of labor rather than reducing the marginal cost of capital. It can be proved that the same result is obtained in both cases. This is because when a firm invests in R&D that increases the marginal productivity of labor, it reduces the marginal cost of capital.

closes its domestic production plant and sets up a new one in a country where wage costs are lower. Firms have to pay a fixed cost to relocate their production plants.

We consider first that firms may invest in R&D independently of their location. We show that when a firm relocates, it invests more in R&D than when it remains in its home country. This means that the two mechanisms (relocation firm and investment in R&D) to reduce marginal production costs are complementary. When a firm moves to a country where wage costs are lower, its market share and profits increase, which permits it to invest more in R&D, and thus to gain additional market share at the expense of its rival. Therefore, the former (latter) firm makes the higher (lower) investment in R&D. Given that the marginal cost of capital depends on the investment in R&D of the firms, when a firm relocates not only its marginal cost of labor is lower but also its marginal cost of capital is lower.

In order to analyze whether R&D investment affects firms' relocation decisions, we consider the case in which firms do not invest in R&D as a benchmark case. We obtain that the range of values of parameters in which at least one firm relocates is wider when firms invest in R&D than in the benchmark case. Therefore, investment in R&D by firms encourages relocation. The reason is that investment in R&D is greater in case of relocation than when firms remain in their home countries. This implies that when a firm relocates both the marginal cost of capital and the marginal cost of labor are lower, which means that profits are higher.

It also can be considered that when a firm relocates it seeks to reduce labor costs and does not invest in R&D (since, for example, firms might employ mainly low-skill workers). However, the firms that remain in the home country invest in R&D to be able to compete with the firms that move abroad. In this case, it is obtained that the range of values of parameters in which at least one firm relocates is smaller than in the benchmark case. This is because the investment made by the firms that remain in the home country partially offsets the cost advantage obtained by the firms that move their production plants abroad, so the incentive to relocate is weaker than in the benchmark case. As a result, when firms invest

in R&D independently of their location, the range of values of parameters in which at least one firm relocates is greater than when firms do not invest in R&D on relocation.

The rest of the paper is organized as follow. Section 2 sets out the model. In Section 3 we consider, as a benchmark case, that firms do not invest in R&D. Section 4 shows the results of the model when firms invest in R&D independently of their locations while Section 5 analyzes the case in which firms do not invest in R&D if they relocate. Finally, Section 6 offers conclusions.

2. The model

We consider an advanced economy made up of two firms, *A* and *B*, producing a homogeneous good. The industry inverse demand function for the product is:

$$p = a - q_A - q_B, \tag{1}$$

where p is the price of the good and q_i is the amount of the good produced by firm i, $i = A, B$.

In order to produce the good firm i uses as production factors labor, L_i, and capital (machines or non labor factors), K_i, according to the following production technology:

$$q_i = Min\{L_i, K_i\},\ i = A, B.$$

Firm i hires L_i workers with a uniform wage rate w_i, $i=A, B$. All workers are unionized and there is an independent union at each firm. The utility function of the union of firm i is:

$$U_i(w_i, L_i) = w_i L_i,\ i=A, B. \tag{2}$$

Unions and firms are both risk neutral. Unions have the objective of income maximization. In order to determine the wage set at each firm, we consider the monopoly-

union model (see Booth, 1995). This model assumes that the unions set the wage and the firms then choose the employment level.

Thus, the cost function of firm i is given by:

$$C(q_i, w_i, x_i) = w_i\, q_i + (c - \beta\, x_i)\, q_i,\ i=A, B. \tag{3}$$

The marginal production cost comprises the marginal cost of labor, w_i, and the marginal cost of capital (when there is no R&D), which is constant and is denoted by c.[9] Equation (3) shows that the marginal cost of labor can be reduced by relocating the firm, and the marginal cost of capital can be reduced by investing in R&D. When a firm relocates it closes its domestic production plant and sets up a new one in a foreign country where wage costs are lower because workers are not unionized. The output of this firm is exported to the advanced country (we thus assume that there is only one market for the good). In order to simplify the analysis, and with no loss of generality, we assume that the wage paid in the foreign country is the reservation wage, which is normalized to zero. Firm i invests amount x_i in R&D, which lowers its marginal cost of capital: $c - \beta\, x_i$. Parameter β determines the rate at which marginal cost of capital, c, declines with an increase in R&D. It shows the productivity of the firm's research effort.

We assume, for the sake of simplicity, that there are no R&D externalities. The cost of R&D is assumed to be quadratic, reflecting the existence of diminishing returns to R&D expenditures (see d'Aspremont and Jacquemin, 1988). Specifically, the cost of R&D of firm i is given by:

$$C(x_i) = \frac{\gamma}{2} x_i^2,\ \gamma > \underline{\gamma},\ i=A, B, \tag{4}$$

[9] We assume that $a>3c$ to simplify the exposition of the results of the model when comparing results obtained in different cases. This assumption does not alter the main results of the paper. If parameter a is interpreted as the size of the market, this restriction implies that the size of the market has to be high enough.

where $\underline{\gamma} = \beta^2(35a + 30c + \sqrt{1225a^2 - 588ac + 900c^2})/(144c)$.[10] Parameter γ is related to the firm's cost effectiveness in R&D technology, so that a low value of the parameter indicates greater efficiency in R&D technology.

When firm i relocates closes its domestic production plant and sets up a new one in a foreign country it has to pay a fixed cost F_i to relocate the plant (i=A, B). Thus, the profit of firm i can be expressed as:

$$\pi_i = (a - q_i - q_j - (w_i + c - \beta x_i))q_i - \frac{\gamma}{2}x_i^2 - F_i,\ i \neq j;\ i, j = A, B, \tag{5}$$

where, F_i=F and w_i=0 if firm i relocates, and F_i=0 and w_i>0 if firm i remains in its home country.

The objective of this paper is to study firms' decisions as to whether to relocate when they invest in R&D to reduce the marginal cost of capital. We consider two cases: (i) firms invest in R&D if they relocate and (ii) firms do not invest in R&D if they relocate. We propose a four stage game with the following timing. In the first stage, firms decide simultaneously whether to relocate. In the second stage, firms decide simultaneously their investments in R&D (if any). In the third stage, unions set wages simultaneously. Finally, in the fourth stage, firms make quantity decisions and hire labor. We solve the game by backward induction from the last stage of the game to obtain a subgame perfect Nash Equilibrium.

We consider first, as a benchmark case, that firms do not invest in R&D independently of their locations.

3. Benchmark case

[10] Condition $\gamma > \underline{\gamma}$ assures that the marginal cost of capital of the firms is positive in all cases ($c - \beta x_i > 0$), and that second order conditions hold.

In this case, as firms do not invest in R&D, there are only three stages. In the first stage, firms decide simultaneously whether to relocate. In the second stage, unions set wages simultaneously. Finally, in the third stage, firms make quantity decisions and hire labor.

There are three subgames to be analyzed: neither firm relocates (denoted by *NN*), only one firm relocates (the superscript *RN* denotes the firm that relocates while *NR* denotes the firm that remains in the home country) and, finally, both firms relocate (denoted by *RR*).

Next we solve the second and third stages of the game when neither firm relocates. In the third stage, firm i chooses the output level that maximizes its profits, given by expression (5), for $F_i=0$ and $x_i=0$, $i=A, B$. Solving this, the equilibrium output (and employment) levels as a function of wage rates are obtained:

$$q_i(w_i, w_j) = L_i(w_i, w_j) = \frac{a - c - 2w_i + w_j}{3}, \quad i \neq j;\ i, j = A, B. \tag{6}$$

In the second stage, unions simultaneously choose the wage that maximizes their utility functions:

$$w_i(w_j) = \underset{w_i}{arg\ max}\ w_i L_i(w_i, w_j),\ i \neq j;\ i, j = A, B, \tag{7}$$

where $L_i(w_i, w_j)$ is given by expression (6). Solving this, the following is obtained:

$$w^{NN} = \frac{a-c}{3},\ q^{NN} = L^{NN} = \frac{2(a-c)}{9},\ \pi^{NN} = \frac{4(a-c)^2}{81}.$$

We now consider that firm j relocates while firm i remains in the country; thus, $F_j=F$, $w_j=0$ and $F_i=0$. In the third stage, each firm chooses the output level that maximizes its profit, given by expression (5), where $x_i=x_j=0$. Solving this, the equilibrium output (and employment) levels as a function of w_i are obtained:

$$q_i(w_i) = L_i(w_i) = \frac{a-c-2w_i}{3},\ q_j(w_i) = L_j(w_i) = \frac{a-c+w_i}{3},\ i\neq j;\ i, j=A, B. \qquad (8)$$

In the second stage, the union of firm i chooses the wage that maximizes its utility function:

$$w_i = \underset{w_i}{arg\ max}\ w_i\, L_i(w_i),\ i\neq j;\ i, j=A, B, \qquad (9)$$

where $L_i(w_i)$ is given by expression (8). Solving this, the following is obtained:

$$w^{NR} = \frac{a-c}{4},\ w^{RN} = 0,\ q^{NR} = L^{NR} = \frac{a-c}{6},\ q^{RN} = L^{RN} = \frac{5(a-c)}{12},$$

$$\pi^{NR} = \frac{(a-c)^2}{36},\ \pi^{RN} = \frac{25(a-c)^2}{144} - F\ .$$

Finally, we consider that both firms relocate. In the third stage, each firm chooses the output level that maximizes its profit, given by expression (5), where $F_j=F_i=F$, $w_j=w_i=0$ and $x_j=x_i=0$. Solving this, the following is obtained:

$$w^{RR} = 0,\ q^{RR} = L^{RR} = \frac{a-c}{3},\ \pi^{RR} = \frac{(a-c)^2}{9} - F\ .$$

Let F_{1B} denote the value of parameter F such that $\pi^{RR} \geq \pi^{NR}$ if and only if $F\leq F_{1B}$, and F_{2B} denote the value of parameter F such that $\pi^{RN} \geq \pi^{NN}$ if and only if $F\leq F_{2B}$, where $F_{2B}>F_{1B}$.[11] Finally, we solve the first stage of the game, obtaining the following result.

Proposition 1. *When the firms do not invest in R&D both firms relocate if $F\leq F_{1B}$, only one firm relocates if $F_{2B}>F>F_{1B}$, and neither firm relocates if $F\geq F_{2B}$.*

Proof. See appendix

[11] The values of parameters F_{1B} and F_{2B} are relegated to the appendix.

Given that the firms do not invest in R&D, the result shown in Proposition 1 is due only to the effects that arise when firms relocate: the relocation of a firm decreases its marginal cost of labor but its marginal cost of capital (c) remains unchanged. We next analyze these effects.

It is easy to see that $w^{NN}>w^{NR}>w^{RN}=w^{RR}=0$ and $q^{RN}>q^{RR}>q^{NN}>q^{NR}$. If a firm relocates, its wage costs decrease ($w^{RN}=w^{RR}=0$), and it gains market share at the expense of the firm that remains in the home country. The former firm produces more and the latter firm less. When both firms relocate their output level is greater than if neither firm relocates since production costs are lower in the first case. As a result, if changing the location of the firm does not require any investment (i.e., $F=0$), then $\pi^{RN} > \pi^{RR} > \pi^{NN} > \pi^{NR}$. This reflects the positive incentive to relocate the firm. This incentive is larger if the other firm does not change its location. But, as setting up a new firm requires an investment ($F>0$), different investment levels will produce different results in equilibrium. In fact, if F is low enough ($F\leq F_{1B}$) both firms find it profitable to relocate. For intermediate values of F ($F_{2B}>F>F_{1B}$) only one firm relocates. In that case, if both firms change their locations the increase in their profits is not large enough to offset the cost of relocation. However, if only one firm relocates the increase in its profit at the expense of its rival offsets the cost of relocation. Finally, if F is high enough ($F\geq F_{2B}$) neither firm relocates since the increase in its profit does not offset the cost of relocation.

4. The firms invest in R&D independently of their locations

In this section we consider that the firms invest in R&D to reduce the marginal cost of capital independently of their locations. Thus, a four stage game must be solved. As in the above section three subgames must be analyzed: neither firm relocates, only one firm relocates and, finally, both firms relocate. We consider first that neither firm relocates.

4.1. Neither firm relocates

We first solve the fourth stage of the game, obtaining the equilibrium in the product market. In this stage, firm *i* chooses the output level that maximizes its profits, given by expression (5), for F_i=0. Solving this, we obtain the equilibrium output and employment levels as a function of wage rates and R&D investments:

$$q_i(w_i(x_i, x_j), w_j(x_i, x_j), x_i, x_j) = \frac{1}{3}(a - c - 2w_i + w_j + 2\beta x_i - \beta x_j),\ i \neq j;\ i, j = A, B. \qquad (10)$$

In the third stage, unions simultaneously choose the wage that maximizes their utility functions:

$$w_i(w_j(x_i, x_j), x_i, x_j) = \underset{w_i}{arg\ max}\ w_i(x_i, x_j)\, L_i(w_i(x_i, x_j), w_j(x_i, x_j), x_i, x_j),\ i \neq j;\ i, j = A, B, \qquad (11)$$

where $L_i(w_i(x_i, x_j), w_j(x_i, x_j), x_i, x_j) = q_i(w_i(x_i, x_j), w_j(x_i, x_j), x_i, x_j)$ is given by expression (10). Solving this, we obtain the wage of the firms, as a function of R&D investments:

$$w_i(x_i, x_j) = \frac{1}{15}(5(a - c) + 7\beta x_i - 2\beta x_j),\ i \neq j;\ i, j = A, B. \qquad (12)$$

It can be shown from equation (12) that the wage paid by firm *i* decreases with the rival's level of R&D ($\partial w_i / \partial x_j < 0$), since it reduces the output level and profits of firm *i*, which means that firm *i* pays a lower wage. In contrast, the wage paid by firm *i* increases with its own investment in R&D ($\partial w_i / \partial x_i > 0$) since it decreases the marginal cost of capital and, thus, increases its market share and profits, which means that it pays a higher wage.

In the second stage, firm *i* (*i*=*A*, *B*) chooses the R&D investment, x_i, that maximizes its profit. Solving this, we obtain the following result.

Lemma 1. *In equilibrium, when neither firm relocates:*

$$x^{NN} = \frac{56\beta(a - c)}{405\gamma - 56\beta^2},\ w^{NN} = \frac{135\gamma(a - c)}{405\gamma - 56\beta^2},\ L^{NN} = q^{NN} = \frac{90\gamma(a - c)}{405\gamma - 56\beta^2},$$

$$\pi^{NN} = \frac{4\gamma(a-c)^2(2025\gamma - 392\beta^2)}{(405\gamma - 56\beta^2)^2}.$$

We now consider that only one firm relocates.

4.2. Only one firm relocates

We now assume that firm *j* relocates while firm *i* remains in the home country. Thus, in the fourth stage, each firm chooses the output level that maximizes its profit, given by expression (5), where $F_j=F$, $w_j=0$ and $F_i=0$. Solving this, we obtain the equilibrium output and employment levels as a function of wage rates and R&D investments:

$$q_j(w_i(x_i, x_j), x_i, x_j) = L_j(w_i(x_i, x_j), x_i, x_j) = \frac{1}{3}(a - c + w_i + 2\beta x_j - \beta x_i),$$
$$q_i(w_i(x_i, x_j), x_i, x_j) = L_i(w_i(x_i, x_j), x_i, x_j) = \frac{1}{3}(a - c - 2w_i - \beta x_j + 2\beta x_i),\ i \neq j;\ i,j=A,B. \quad (13)$$

In the third stage, the union of firm *i* chooses the wage that maximizes its utility function:

$$w_i(x_i, x_j) = \arg\max_{w_i} w_i(x_i, x_j)\, L_i(w_i(x_i, x_j), x_i, x_j),\ i \neq j;\ i, j=A, B. \quad (14)$$

Solving this, we obtain the wage paid by firm *i* as a function of R&D investments:

$$w_i(x_i, x_j) = \frac{1}{4}(a - c - \beta x_j + 2\beta x_i),\ i \neq j;\ i, j=A, B. \quad (15)$$

In the second stage, firms simultaneously choose the R&D investment that maximizes their profits. Solving this, we obtain the following result.

Lemma 2. *In equilibrium, when only one firm relocates:*

$$x^{NR}=\frac{4\beta(a-c)(6\gamma-7\beta^2)}{216\gamma^2-195\gamma\beta^2+28\beta^4},\ x^{RN}=\frac{7\beta(a-c)(15\gamma-4\beta^2)}{216\gamma^2-195\gamma\beta^2+28\beta^4},\ w^{RN}=0,$$

$$w^{NR}=\frac{9\gamma(a-c)(6\gamma-7\beta^2)}{216\gamma^2-195\gamma\beta^2+28\beta^4},\ q^{RN}=L^{NR}=\frac{6\gamma(a-c)(15\gamma-4\beta^2)}{216\gamma^2-195\gamma\beta^2+28\beta^4},$$

$$q^{NR}=L^{RN}=\frac{6\gamma(a-c)(6\gamma-7\beta^2)}{216\gamma^2-195\gamma\beta^2+28\beta^4},\ \pi^{NR}=\frac{4\gamma(a-c)^2(9\gamma-2\beta^2)(6\gamma-7\beta^2)^2}{(216\gamma^2-195\gamma\beta^2+28\beta^4)^2},$$

$$\pi^{RN}=\frac{\gamma(a-c)^2(72\gamma-49\beta^2)(15\gamma-4\beta^2)^2}{2(216\gamma^2-195\gamma\beta^2+28\beta^4)^2}-F.$$

Finally, we consider that both firms change their locations.

4.3. Both firms relocate

In the fourth stage of the game, each firm chooses the output level that maximizes its profit, given by expression (5), where $F_j=F_i=F$ and $w_j=w_i=0$. Solving this, we obtain the equilibrium output and employment levels as a function of wage rates and R&D investments:

$$q_i(x_i, x_j)=L_i(x_i, x_j)=\frac{1}{3}(a-c+2\beta x_i-\beta x_j)\ ,\ i\neq j;\ i, j=A, B. \tag{16}$$

In this case there is no third stage since the wage is exogenously given. In the second stage, the firms simultaneously choose R&D investments that maximize their profits. Solving this, we obtain the following result.

Lemma 3. *In equilibrium, when both firms relocate:*

$$x^{RR}=\frac{4\beta(a-c)}{9\gamma-4\beta^2},\ w^{RR}=0,\ q^{RR}=L^{RR}=\frac{3\gamma(a-c)}{9\gamma-4\beta^2},\ \pi^{RR}=\frac{\gamma(a-c)^2(9\gamma-8\beta^2)}{(9\gamma-4\beta^2)^2}-F.$$

Next we compare the results obtained in the three cases considered.

4.4. Comparison of the three cases

Comparing the results obtained in Lemmas 1 to 3 we obtain the following result.

Proposition 2. *When firms invest in R&D when they relocate, in equilibrium:*
i) $x^{RN} > x^{RR} > x^{NN} > x^{NR}$*;*
ii) $w^{NN} > w^{NR} > w^{RN} = w^{RR} = 0$, $q^{RN} > q^{RR} > q^{NN} > q^{NR}$.

Proof. See Appendix

This proposition shows that when a firm relocates, independently of whether its rival decides to relocate or not, it invests more in R&D than when it remains in the home country. When only one firm relocates its marginal cost of labor decreases and thus its market share and profits increase, which enables it to make invest more in R&D and gain additional market share at the expense of its rival since its marginal cost of capital decreases. Therefore, the former (latter) firm makes the higher (lower) investment in R&D. As a result, when a firm relocates it reduces its marginal cost of labor, which implies more investment in R&D and thus marginal production costs are additionally reduced.

As seen above, the wage of firm *i* decreases with the rival's level of R&D ($\partial w_i / \partial x_j < 0$) and increases with its own investment in R&D ($\partial w_i / \partial x_i > 0$). Thus, as $x^{NN} > x^{NR}$ it is obtained that $w^{NN} > w^{NR} > 0$. Finally, given that firms that relocate pay lower wages and invest more in R&D they produce more ($q^{RN} > q^{RR} > q^{NN} > q^{NR}$).

It remains to solve the first stage of the game, in which firms decide whether to relocate or not.

4.5. Firms decide whether to relocate

Let F_1 denote the value of parameter F such that $\pi^{NR} \geq \pi^{RR}$ if and only if $F \geq F_1$, and F_2 denote the value of parameter F such that $\pi^{RN} \geq \pi^{NN}$ if and only if $F \leq F_2$, where $F_2 > F_1$.[12] Solving the first stage of the game, the following result is obtained.

Proposition 3. *When firms invest in R&D when they relocate: both firms relocate if* $F \leq F_1$*, only one firm relocates if* $F_1 < F < F_2$ *and, neither firm relocates if* $F \geq F_2$.

Proof. See Appendix

It is immediately apparent that if relocating the firm entails no cost (i.e. if $F=0$), it is obtained that $\pi^{RN} > \pi^{RR} > \pi^{NN} > \pi^{NR}$. If $F=0$, when firm i relocates, it reduces its marginal cost of labor ($w_i=0$) since there is no wage bargaining in the new location. Additionally, when firm i relocates it invests more in R&D, which reduces the marginal cost of capital. This last effect reinforces the first one and, as a result, the total marginal production cost of the firm that relocates decreases. This has a stronger effect on profits than the greater expenditure in R&D. As a result, when a firm relocates (independently of the decision made by its rival) it obtains higher profits. Therefore, if relocating a firm does not entail any cost ($F=0$), both firms have a positive incentive to relocate and, thus, in equilibrium they both do so.

When relocating entails a positive cost ($F>0$) a negative effect appears that reduces the incentive of firms to relocate. In fact, when the fixed cost, F, is low enough ($F \leq F_1$) the positive incentive to relocate is stronger than the negative one in both firms and, thus, both firms change their locations. When F is high enough ($F \geq F_2$) neither firm relocates since the negative incentive to relocate is stronger than the positive one in both firms. Finally, for intermediate values of F ($F_1 < F < F_2$), if only one firm relocates that firm gains market share and profits at the expense of its rival, which makes the positive effect large enough

[12] The values of parameters F_1 and F_2 are relegated to the appendix.

to offset the negative one in the firm that relocates. As a result, only one firm changes relocates.

Next we compare the results obtained in Propositions 1 and 3 to study whether investment in R&D by firms encourages relocation or not.

Proposition 4. *When firms invest in R&D independently of their location, the range of value of parameters for which at least one firm relocates is wider than in the benchmark case.*

Proof. See Appendix

This proposition shows (see Figure 1) that investment in R&D by firms encourages relocation. Proposition 2 shows that investment in R&D is greater in case of relocation than when the firms remain in the home country. This implies that when a firm relocates both the marginal cost of capital and the marginal cost of labor are lower, which means that profits are higher. As a result, when firms invest in R&D they relocate for a wider range of parameter values than in the benchmark case.

[INSERT FIGURE 1]

When $F_{1B}<F\leq F_1$ only one firm relocates in the benchmark case while both firms do so when firms invest in R&D. In the benchmark case, if both firms relocate the increase in their profits due to the lower marginal cost of labor is not large enough to offset the cost of relocation. However, when firms invest in R&D the lower marginal cost of capital combined with the lower marginal cost of labor in case of relocation generates an increase in their profits that offsets the cost of relocation. When $F_{2B}<F\leq F_2$ neither firm relocates in the benchmark case since the increase in their profits does not offset the fixed cost F. However, when firms invest in R&D if one firm does not relocate the other one does, since the latter firm makes a greater investment in R&D, which decreases its marginal cost of capital and increases its profits on the benchmark case. Thus, if only one firm relocates it gains market share and profits at the expense of its rival, which offsets the fixed cost that it

has to pay. Finally, for the remaining parameter values the two firms make the same relocation decision in both cases.

5. Only firms that do not relocate invest in R&D

We now consider that firms invest in R&D only if they do not relocate their production plants. Thus, investment in R&D is a way of avoiding a loss of competitiveness regarding firms that relocate. We have to analyze three subgames: neither firm relocates, only one firm relocates, and both firms relocate. Solving these subgames and comparing them (see Appendix), we obtain the following result.

Proposition 5. *When firms do not invest in R&D when they relocate, in equilibrium:*
i) $x^{NN} > x^{NR} > x^{RN} = x^{RR} = 0$*;*
ii) $w^{NN} > w^{NR} > w^{RN} = w^{RR} = 0$, $q^{RN} > q^{RR} > q^{NN} > q^{NR}$.

Proof. See Appendix

This proposition shows that a firm invests more in R&D if its rival remains in the home country than if it relocates ($x^{NN}>x^{NR}$). When only one firm relocates, its marginal cost of labor decreases and, thus, the firm that remains in the home country loses market share and profits at the expense of its rival. As a result, the firm that does not relocate invests less in R&D than if its rival remains in the home country. Given that the wage of firm *i* increases with its own investment in R&D, when a firm does not relocate it pays higher wages when its rival remains in the home country than when its rival relocates ($w^{NN}>w^{NR}$). When only one firm relocates its marginal labor cost decreases, which has a greater effect than the reduction in the marginal cost of production of the firm that remains in the home country. Thus, the firm that relocates gains market share and profits at the expense of its rival. Therefore: $q^{RN} > q^{RR} > q^{NN} > q^{NR}$.

It remains to solve the first stage of the game. In that stage, firms decide whether to relocate or not. Solving the first stage we obtain the following result.

Proposition 6. *When firms do not invest in R&D when they relocate: both firms relocate if* $F \leq F_{1N}$*, only one firm relocates if* $F_{1N} < F < F_{2N}$*, and neither firm relocates if* $F \geq F_{2N}$.[13]

Proof. See Appendix

There is a positive incentive for a firm to relocate: its marginal cost of labor and, therefore, its marginal production cost decreases since there is no wage bargaining. However, as firms have to pay the cost of setting up a new firm, there is a negative effect. In this case only firms that remain in the home country invest in R&D, which reduces the production cost of the firms that do not relocate. This is also a negative incentive to relocate.

When the fixed cost, F, is low enough ($F \leq F_{1N}$) the positive incentive to relocate is stronger than the negative ones in both firms and, thus, both firms relocate. When F is high enough ($F \geq F_{2N}$) neither firm relocates since the negative incentives to relocate are stronger than the positive one in both firms. Finally, for intermediate values of F ($F_{1N} < F < F_{2N}$), if only one firm relocates that firm gains market share and profits at the expense of its rival, which makes the positive effect large enough to offset the negative ones in the firm that relocates. As a result, only one firm relocates.

Next we compare the results obtained in Proposition 1 and 6 to study whether the investment in R&D by firms encourages relocation or not. This result is illustrated in Figure 2.

Proposition 7. *When only firms that do not relocate invest in R&D, the range of values of parameters for which at least one firm relocates is narrower than in the benchmark case.*

Proof. See Appendix

[INSERT FIGURE 2]

[13] The values of parameters F_{1N} and F_{2N} are relegated to the appendix.

This proposition shows (see Figure 2) that as firms that do not relocate may invest in R&D to increase their competitiveness, the incentive to relocate is weaker than in the benchmark case. This implies that firms that do not relocate have a lower marginal cost of capital than those that do; however, the marginal cost of labor is greater. As a result, firms relocate for a narrower range of parameter values than in the benchmark case.

When $F_{1N}<F\leq F_{1B}$ both firms relocate in the benchmark case while only one firm does do when domestic firms invest in R&D. In the benchmark case, if both firms relocate the increase in their profits is large enough to offset the cost of relocation. However, when domestic firms invest in R&D the lower marginal cost of capital generates an increase in their profits that offsets the cost of relocation for only one firm. When $F_{2N}<F\leq F_{2B}$ only one firm relocates in the benchmark case since the increase in the profits of the firms offsets the fixed cost F only for one firm. When domestic firms invest in R&D neither of them relocates. Finally, for the remaining parameter values the two firms make the same relocation decision in both cases.

6. Conclusions

The literature studying the location decisions of firms does not take into account that when firms move to new locations abroad their established knowledge may need to be adapted to the circumstances prevailing there, which may justify investment in R&D.

The literature on foreign direct investments (FDI) has considered firms' location decisions and firms' R&D investment decisions endogenously and simultaneously, showing that investment in R&D encourages firms to expand abroad via FDI instead of via exports. However, this literature assumes that firms maintain their domestic plants. There is empirical evidence to indicate that many firms are closing their plants in advanced countries to relocate in countries with lower wage costs. We therefore study how firms' decisions as to whether to relocate to a country with non-unionized workers and, thus, with a lower marginal cost of labor, are affected by the fact that firms invest in R&D to reduce their marginal cost of capital.

We show that when a firm relocates it invests more in R&D than when it remains in the home country. When a firm moves to a country where wage costs are lower, its market share and profits increase, which permits it to invest more in R&D and gain additional market share at the expense of its rival. Therefore, the former (latter) firm makes the higher (lower) investment in R&D. Given that the marginal cost of capital depends on investment in R&D by firms, when a firm relocates both its marginal cost of labor and its marginal cost of capital are lower and, thus, its profit is higher.

In order to analyze whether R&D investments affect firms' relocation decisions, we consider as a benchmark the case in which firms do not invest in R&D. We obtain that the range of values of parameters for which at least one firm relocates is wider when firms invest in R&D than in the benchmark case. Therefore, investment in R&D by firms encourages relocation.

It could be considered that when a firm relocates it seeks to reduce labour costs and does not invest in R&D. However, firms that remain in the home country invest in R&D to be able to compete with firms that have moved abroad. It can be shown that in that case the range of parameter values for which at least one firm relocates is narrower than in the benchmark case. Therefore, when firms invest in R&D independently of their location, the range of parameter values for which at least one firm relocates is wider than when firms do not invest in R&D in case of relocation.

As an extension, we have analyzed whether firms' relocation is optimal from a social welfare point of view in the two cases considered. It can be shown that in both cases the number of firms that relocate is not lower than socially desirable. This is because firms take into account only their own profits while social welfare comprises the consumer and producer surpluses and the utility of workers.[14]

Acknowledgements

[14] The proof is available from the authors on request.

Financial support from Ministerio de Ciencia y Tecnología and FEDER (ECO2009-07939) and Departamento de Educación, Universidades e Investigación del Gobierno Vasco (IT-223-07) is gratefully acknowledged.

Appendix

Proof of Proposition 1

Comparing the profit obtained by the firms in the three cases, we obtain the following: $\pi^{RR}-\pi^{NR}=\frac{(a-c)^2}{12}-F\geq 0$ if and only if $F\leq F_{1B}$; $\pi^{RN}-\pi^{NN}=\frac{161(a-c)^2}{1296}-F\geq 0$ if and only if $F\leq F_{2B}$, where $F_{2B}=\frac{161(a-c)^2}{1296}>F_{1B}=\frac{(a-c)^2}{12}$.

Proof of Proposition 2

i) $x^{RN}-x^{RR}=-\frac{27\beta\gamma(a-c)(4\beta^2+3\gamma)}{(4\beta^2-9\gamma)(28\beta^4-195\beta^2\gamma+216\gamma^2)}>0 \ \forall \ \gamma>\underline{\gamma}$,

ii) $x^{RR}-x^{NN}=\frac{1116\beta\gamma(a-c)}{224\beta^4-2124\beta^2\gamma+3645\gamma^2}>0 \ \forall \ \gamma>\underline{\gamma}$,

iii) $x^{NN}-x^{NR}=-\frac{36\beta\gamma(a-c)(49\beta^2+66\gamma)}{(56\beta^2-405\gamma)(28\beta^4-195\beta^2\gamma+216\gamma^2)}>0 \ \forall \ \gamma>\underline{\gamma}$.

Therefore $x^{RN}>x^{RR}>x^{NN}>x^{NR}$. Finally, as $\gamma>\underline{\gamma}$, comparing the wages paid by firms we obtain:

$$w^{NN}-w^{NR}=-\frac{18(a-c)\gamma(14\beta^4+123\beta^2\gamma+405\gamma^2)}{(56\beta^2-405\gamma)(28\beta^4-195\beta^2\gamma+216\gamma^2)}>0;$$

Proof of proposition 3

Let $F_1 = (243\ (a-c)^2\ \gamma^2\ (112\ \beta^8 - 984\ \beta^6\gamma + 2751\ \beta^4\gamma^2 - 3168\ \beta^2\gamma^3 + 1296\ \gamma^4)) / ((4\beta^2 - 9\gamma)^2\ (28\ \beta^4 - 195\ \beta^2\gamma + 216\ \gamma^2)^2)$, and $F_2 = (81\ (a-c)^2\ \gamma^2\ (131712\ \beta^8 - 2162384\ \beta^6\gamma + 12593760\ \beta^4\gamma^2 - 30239289\ \beta^2\gamma^3 + 23473800\gamma^4)) / (2\ (56\ \beta^2 - 405\gamma)^2\ (28\ \beta^4 - 195\ \beta^2\gamma + 216\ \gamma^2)^2)$.

Comparing the profits obtained by the firms: $\pi^{NR} - \pi^{RR} > 0$ if and only if $F > F_1$, and $\pi^{RN} - \pi^{NN} > 0$ if and only if $F < F_2$, where $F_2 - F_1 = (81\ (a-c)^2\ \gamma^3\ (4915456\ \beta^{10} - 61932576\ \beta^8\gamma + 210992400\ \beta^6\gamma^2 - 21080898\ \beta^4\gamma^3 - 668989449\ \beta^2\gamma^4 + 625919400\ \gamma^5))/(2\ (56\ \beta^2 - 405\ \gamma)^2\ (4\beta^2 - 9\ \gamma)^2\ (28\ \beta^4 - 195\ \beta^2\ \gamma + 216\ \gamma^2)^2) > 0\ \forall\ \gamma > \underline{\gamma}$.

Proof of proposition 4

i) $F_2 - F_{2B} = -(((a-c)^2\ \beta^2\ (395838464\ \beta^{10} - 11238984960\ \beta^8\gamma + 118844807760\ \beta^6\gamma^2 - 583440518808\ \beta^4\gamma^3 + 1301333124321\ \beta^2\gamma^4 - 978139126728\ \gamma^5))\ /\ (1296\ (56\ \beta^2 - 405\ \gamma)^2\ (28\ \beta^4 - 195\ \beta^2\ \gamma + 216\ \gamma^2)^2)) > 0\ \forall\ \gamma > \underline{\gamma}$,

ii) $F_1 - F_{1B} = -(((a-c)^2\ \beta^2\ (12544\ \beta^{10} - 231168\ \beta^8\gamma + 1325088\ \beta^6\gamma^2 - 2971728\ \beta^4\gamma^3 + 2849661\ \beta^2\gamma^4 - 944784\gamma^5))\ /\ (12\ (4\ \beta^2 - 9\ \gamma)^2\ (28\ \beta^4 - 195\ \beta^2\gamma + 216\gamma^2)^2)) > 0\ \forall\ \gamma > \underline{\gamma}$.

iii) $F_{2B} - F_1 = ((a-c)^2\ (2019584\ \beta^{12} - 37218048\ \beta^{10}\gamma + 230648544\ \beta^8\gamma^2 - 630523440\ \beta^6\gamma^3 + 883956969\ \beta^4\gamma^4 - 641718288\ \beta^2\gamma^5 + 200294208\ \gamma^6))\ /\ (1296\ (4\ \beta^2 - 9\ \gamma)^2\ (28\ \beta^4 - 195\ \beta^2\gamma + 216\gamma^2)^2)) > 0\ \forall\ \gamma > \underline{\gamma}$.

Only firms that do not relocate invest in R&D

Neither firm relocates. In this case, as both firms remain in the home country they both invest in R&D. Thus, the same result as in Lemma 1 is obtained.

We now assume that firm *j* relocates while firm *i* remains in the home country. Therefore, only firm *i* invests in R&D. Thus, in the fourth stage of the game each firm chooses the output level that maximizes its profit, given by expression (5), where $F_j = F$, $w_j = 0$ and $F_i = 0$. Solving this, the following is obtained:

$$q_i(w_i(x_i), x_i) = L_i(w_i(x_i), x_i) = (a - c - 2w_i + 2\beta x_i)/3,$$

$$q_j(w_i(x_i), x_i) = L_j(w_i(x_i), x_i) = (a - c + w_i - \beta x_i)/3,\ i \neq j;\ i,j = A,B.$$

In the third stage, the union of firm i chooses the wage that maximizes its utility function. Solving this, we obtain: $w_i(x_i)=(a-c+2\beta x_i)/4$, $i = A, B$. In the second stage of the game, firms simultaneously choose the R&D investment that maximizes their profits. Solving this, we obtain:

$$x^{NR}=\frac{\beta(a-c)}{9\gamma-2\beta^2},\ x^{RN}=0,\ w^{NR}=\frac{9\gamma(a-c)}{4(9\gamma-2\beta^2)},\ w^{RN}=0,\ q^{RN}=L^{RN}=\frac{(15\gamma-4\beta^2)(a-c)}{4(9\gamma-2\beta^2)},$$

$$q^{NR}=L^{RN}=\frac{3\gamma(a-c)}{2(9\gamma-2\beta^2)},\ \pi^{NR}=\frac{\gamma(a-c)^2}{4(9\gamma-2\beta^2)},\ \pi^{RN}=\frac{(15\gamma-4\beta^2)^2(a-c)^2}{16(9\gamma-2\beta^2)^2}-F.$$

Next we consider that both firms relocate. In this case, as $x_j=x_i=0$, the same result as in the benchmark case is obtained.

In the first stage of the game firms decide whether to relocate or not. Let F_{1N} denote the value of parameter F such that $\pi^{NR}\geq\pi^{RR}$ if and only if $F\geq F_{1N}$, and F_{2N} denote the value of parameter F such that $\pi^{RN}\geq\pi^{NN}$ if and only if $F\leq F_{2N}$, $F_{2N}>F_{1N}$, $F_{1N}=((a-c)^2(8\beta^2-27\gamma))/(36(2\beta^2-9\gamma))$ and $F_{2N}=((a-c)^2(50176\beta^8-1001728\beta^6\gamma+7351632\beta^4\gamma^2-23191272\beta^2\gamma^3+26408025\gamma^4))/(16(56\beta^2-405\gamma)^2(2\beta^2-9\gamma)^2)$.

As $\gamma>\chi$ we obtain: $F_{2N}-F_{2B}=((a-r)^2\beta^2(511168\beta^6-8437968\beta^4\gamma+46511739\beta^2\gamma^2-84066093\gamma^3))/(324(56\beta^2-405\gamma)^2(2\beta^2-9\gamma)^2)<0$, and $F_{1N}-F_{1B}=((a-c)^2\beta^2)/(18(2\beta^2-9\gamma))<0$.

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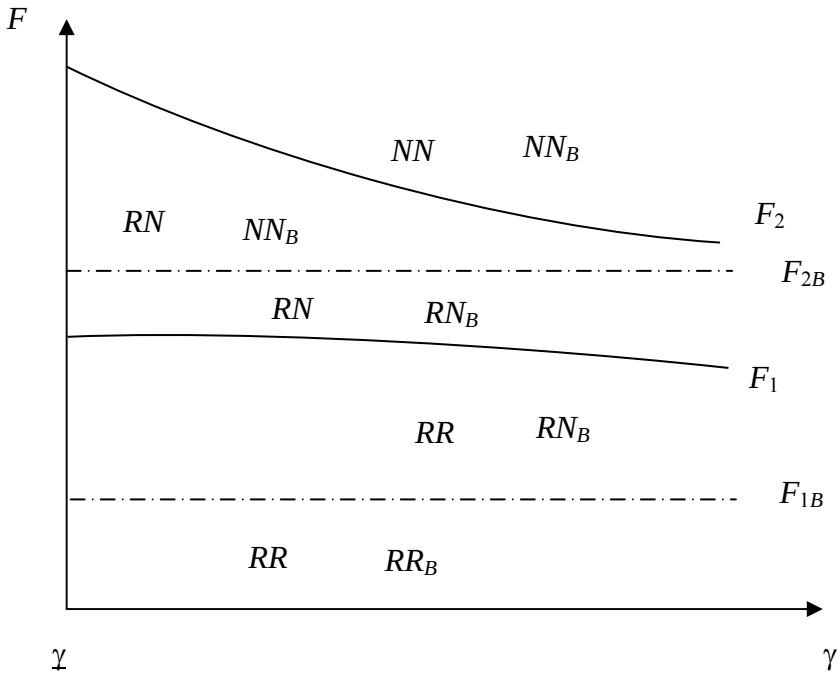

Figure 1. Illustration of Proposition 4

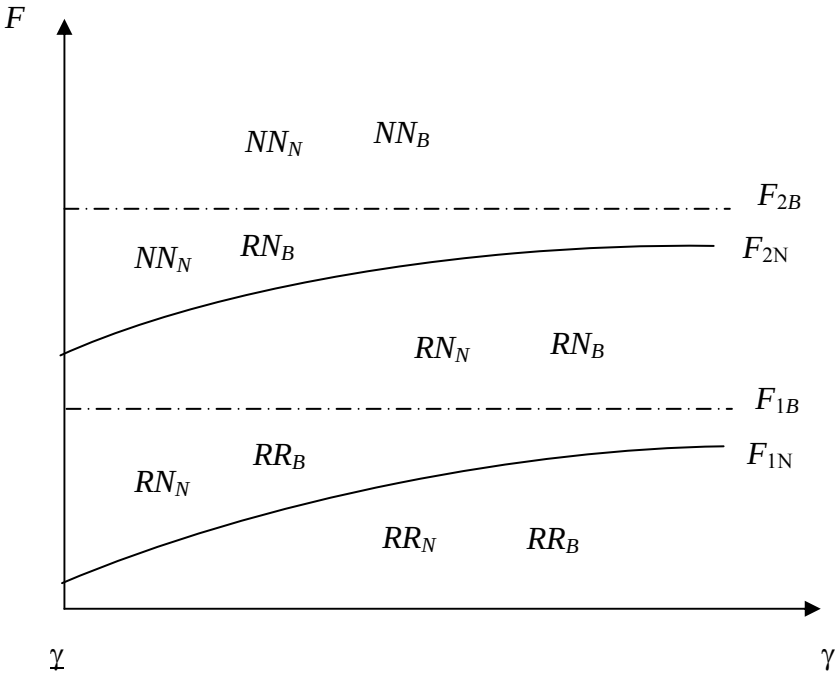

Figure 2. Illustration of Proposition 7