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**R&D, Strategic Investment and
Multinational Choice**

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R&D, Strategic Investment, and Multinational Choice*

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Abstract

We analyze the influence of strategic R&D investment on the firms' mode of foreign expansion: export *versus* multinational. Strategic investment allows a firm, not only to improve its own level of productive efficiency (as in the no-strategic investment case), but also to affect rivals' strategic choices (exit-entry, mode of entry, R&D and outputs). Different strategic investment capacities between firms conduce to endogenous competitiveness asymmetries: firms with higher ability to strategically invest tend to invest more in R&D and as such to be more competitive. As a result these firms have higher propensity to become multinational and they use this advantage to compel rivals not to enter the market or in case of entry to force them to the domestic strategy. This can help to explain asymmetric FDI (foreign direct investment) patterns, given that countries that host firms with more power to strategically invest can lead the world markets in terms of multinational activity. In addition, we find that trade is inversely related with the R&D intensity of a sector and the strategic investment capacity of firms. Then international trade patterns can be directly affected by firms themselves.

Keywords: Mode of Entry, R&D Investment, Multinationals, Strategic Investment.

JEL Classification: F23, C72, L10.

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1 Introduction

Foreign direct investment (FDI) and R&D investment are two core issues in today's world economy. Concerning the first, the multinational strategy is one of the preferred modes of foreign expansion by firms, rivaling directly with the export strategy. In fact not only FDI flows, FDI stocks and sales by foreign affiliates have constantly grown in the last decades, but also FDI flows have grown faster than GDP and trade flows (UNCTAD, 1996). Furthermore, multinational firms (MNF) represent the large bulk of world trade and FDI (UNCTAD, 1996). On the other hand, R&D investment is central in international competition dynamics. Not surprisingly, R&D competition is of particular relevance in-between firms involved in multinational activity, suggesting that R&D investment and FDI are closely linked (for evidence see for example Morck and Yeung, 1992; and Grubaugh, 1987). In reality, as shown by Kravis and Lipsey (1992) empirical study on US multinationals, high R&D investment by individual firms is associated with high multinationals shares. Also, the competitiveness of US multinationals seems to be determined by the level of investment in firm specific assets, such as R&D investment (Kravis and Lipsey, 1992). Not surprisingly in the US, MNFs account for 80% of total R&D expenditure by private firms (Graham, 1996). All this evidence suggests that it is important to analyze how R&D investment affects FDI and *vice-versa*.

In terms of related economic literature, however, the two issues have mainly been dealt with separately. On the side of innovation, there is an extensive literature on the effects of process R&D in oligopolist-duopolist markets. We mention here some examples. Fudenberg and Tirole (1984) show that in a Cournot-duopoly setting firms strategically over-invest in R&D in order to promote exit by rivals. Nevertheless, this strategic incentive might be weakened in the presence of technological spillovers, as in Spence (1984). In turn, d'Aspremont and Jacquemin (1988) demonstrate that R&D cooperation may internalize this externality, promoting firms to enter in cooperative R&D relations as research joint-ventures¹. Learning by doing can also induce some strategic behavior by firms. For example in Fudenberg and Tirole (1983), when firms compete in outputs they have incentives to accumulate experience at an early stage so as to deter entry by potential entrants². Instead, Spencer and Brander (1983) Leahy and Neary (1997) and Neary and Leahy (2000) look at the implications of R&D investment on industrial policy in the context of the strategic trade policy literature³. These studies indicate that in some cases R&D competition may justify R&D subsidies in order to make the usual profit-shifting effect from the foreign firms to the domestic ones. Also, Neary (2002a,b) in a open economy setup analyzes the effects of R&D investment and trade on industrial structure, cross-border mergers and the increase in skill-premium between skilled and unskilled-workers.

In turn, theory on FDI is mainly divided into two branches: vertical and

¹ See also Kamien *et al.* (1992) and Suzumura (1992).

² See also Spence (1981) and Leahy and Neary (1999).

³ See also Bagwell and Staiger (1994) and Barros and Nilssen (1999).

horizontal FDI. The first is defined by the production of complementary parts of a good or execution of successive phases of the production process in different countries, such that vertical relations connect plants from the same firm. The second refers to the production of the same good in different countries in plants directed for local production. The two most influential papers in vertical and horizontal FDI are respectively Helpman (1984) and Horstmann and Markusen (1992). Helpman (1984) looks at vertical FDI by considering that firms have headquarters that supply specialized services (such as R&D, advertising, strategic planning and so on) to plants, without incurring trade costs. The decision to become multinational consists of locating the plant away from the headquarters. He further assumes that countries differ in factor endowments and that the headquarters and the plant use production factors in different intensities. Consequently, firms may find it advantageous to locate each segment of the firm in the country that is abundant in the factor of production that the headquarters and the plant respectively use more intensively.

Horstmann and Markusen (1992), on the other hand, study horizontal FDI. Firms decide between exporting (domestic firm option) or establishing a second plant in the foreign market (multinational firm option). It is assumed that there are fixed costs at firm level (R&D, blueprints, patents and so on), plant-specific fixed costs and increasing returns in production. The choice to become multinational depends on a trade-off between concentration of plants and proximity to consumers. This trade-off is determined by the interplay between trade costs and the fixed cost of opening a new plant. Namely, the multinational option is favored when plant-specific fixed costs are low relative to trade costs.

Literature on vertical and horizontal FDI therefore makes endogenous the choice to become multinational, but it does not take into consideration R&D investment. Some other papers instead analyze the innovative activities of MNCs, but multinationality is exogenous (de Bondt *et al.*, 1988; Veugelers and Vanden Houte, 1990; and Wang and Blomstrom, 1992), i.e.: firms do not face the decision between being domestic or multinational, they are assumed to be *à priori* MNCs. To our knowledge, only in Petit and Sanna-Randaccio (2000) both the firms' mode of foreign expansion and R&D investment are endogenously determined. By doing this, they are able to show that R&D investment increases the probability of multinational expansion by individual firms.

The analysis developed here follows from one side Horstmann and Markusen (1992) by assuming only horizontal FDI⁴ and, from another side, Petit and Sanna-Randaccio (2000) by introducing process R&D investment. One of the objectives of this paper is therefore to assess the effects of innovative activities on the firms' mode of foreign expansion. As a result of this, then, contrary to

⁴Vertical FDI could be easily introduced in our model by allowing for international differences in factor endowments, as in Helpman (1984). However, for simplification purposes and to center our analysis in the role of R&D investment *per se*, we have opted only to consider horizontal FDI. Furthermore, and as defended by Markusen and Maskus (2001), empirical evidence gives more support to the horizontal approach to multinationality, rather than to the vertical approach. In fact, not only most of the output of foreign affiliates is sold in the host country, but also there is little evidence that FDI is related with international differences in factor endowments (see also Brainard, 1997).

Horstmann and Markusen (1992), we are able to make endogenous the firm-specific fixed costs, given that R&D investment determines the level of these costs. This is particularly important, since firm-specific fixed costs are intended to represent strategic assets as R&D investment that can hardly be thought of as exogenous.

The world economy consists of two identical countries, each with one potential entrant firm in the increasing returns sector. The decision between the domestic and the multinational option is, like in Horstmann and Markusen (1992), a trade-off between proximity to consumers and the cost of having an additional plant.

Furthermore, three games are considered that differ in the type of R&D investment performed by firms. In the first game all firms invest strategically, in the second all firms invest non-strategically, while in the third game the home firm invests strategically and the foreign firm non-strategically. We call these games respectively: strategic investment game, non-strategic investment game, and home strategic investment game. Strategic investment means that firms commit themselves more fully to the investment process, in the sense that the R&D choices interact with the output choices. Instead non-strategic investment, though R&D takes place, is not so linked to outputs. Therefore, in the strategic mode, an intermediate stage is introduced in the game, where firms decide first on the investment policy and then on output. Non-strategic behavior translates on a joint decision, at a single stage, on R&D and outputs. The consequence of this is that strategic R&D investment can be used by a firm not only to improve its own efficiency (as in the non-strategic case) but also to affect rivals' strategic choices: exit-entry, mode of entry, R&D investment and outputs. For that reason, when a firm that can invest strategically competes with a firm that cannot do so, the first has an advantage over the second. Then, asymmetric strategic investment capacities can be a good tool to introduce endogenous asymmetries between firms, because these differences are internalized on the firms' R&D choices (and therefore efficiency levels).

As such, the timing of the three games is the following. In the strategic investment game there are three stages. In the first-stage, firms make the entering decision: entering *versus* non-entering; and in case of entering, firms' choose between a one-plant (domestic-exporting firm) or a two-plant strategy (multinational firm). In the second-stage, firms set the optimum level of R&D investment, in order to achieve future reductions in marginal costs. In the third-stage, firms compete in quantities *à la* Cournot. In the non-strategic game there are only two stages: the first is as above but in the second there is a simultaneous choice of R&D and output levels, for both the home and foreign firm. Finally, in the home strategic investment game, the home firm acts as in the strategic investment game while the foreign firm acts as in the non-strategic investment game (i.e.: the foreign firm does not move in the second stage and chooses outputs and R&D levels in the third stage). In all games, market structure is thus endogenously determined as the Nash-equilibrium of a multi-stage game⁵.

⁵Our model differs from Petit and Sanna-Randaccio (2000) in that we consider the effects

One question then arises: when in the real world can firms have different abilities to invest strategically in R&D? One example can be firms that are from countries in different stages of development: home as a more technologically advanced, developed country, while foreign is a developing economy. Firms in the foreign country will either be structurally unable or lack the resources to make a more encompassing R&D commitment. However, this can also be the case among firms from developed countries, we just need to think of two firms with different organizational capabilities, financial resources, research reputation, quality of the scientific-labor force and so on. In all cases this happens because R&D choices permanently affect output choices. Then, there exists a kind of sunk-cost in R&D that the firm needs to hold on to in the output stage. In our opinion, it is reasonable to believe that not all firms have the capacity to do so.

Besides this section, this paper has another eight sections. In the next section the base-line model is introduced. In sections 3 and 4 we derive expressions for outputs and R&D investment levels under the different strategic investment games considered. In section 5, some comparative static exercises are performed. Afterwards, we extract some implications of the R&D duopoly model in terms of international trade. In section 7 we find the equilibrium of the entry stage. In section 8, we perform some robustness tests. We conclude by discussing results.

2 The Model

The multinational R&D model of this paper is developed with the same basic structure as in Horstmann and Markusen (1992). This is done to allow a more direct comparison between our model and that of Horstmann and Markusen (hereinafter HM). In this sense, as in HM, we assume that the international market for the oligopolist sector can only profitably support two firms: one home firm and one foreign firm. Furthermore, the world economy consists of two countries (home and foreign), two sectors (the increasing returns duopolist sector and the perfect competition sector, that produce the *IRS*-good and the *CRS*-good respectively), and one factor of production (labor).

We consider quasi-linear preferences in the two goods with a quadratic sub-utility in the good produced by the duopolist sector:

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

And similarly for the foreign country, noting that $a = a^*$, $b = b^*$, and $q_0 = q_0^*$. Where, $Q = q + x^*$ represent the total sales of the *IRS*-good in the home country, and $Q^* = q^* + x$ sales in the foreign country. The variables of interest are q : sales of the home firm in the home market; x : sales of the home firm in the foreign market; q^* : sales of the foreign firm in the foreign market;

of having firms with different abilities to invest strategically in R&D.

x^* : sales of the foreign firm in the home market; and q_0 consumption of the traditional good⁶.

Further, each individual is endowed with a unit of labor (from where they get their income, I), and $\bar{q}_0 > 0$ units of the traditional good⁷. Then, home consumers have the following budget constraint:

$$PQ + q_0 = I + \bar{q}_0 \quad (2)$$

From this maximization problem we can get the indirect demand:

$$P = a - bQ \quad (3)$$

To find the direct demand it suffices to solve the previous expression for total sales:

$$Q = \frac{a}{b} - \frac{1}{b}P \quad (4)$$

Also like in HM, we assume that firms have to bear three types of costs: marginal costs (C), firm-specific fixed costs (Γ) and plant-specific fixed costs (Δ); and that the multinational activity is introduced through Δ .

Since we consider process R&D investment, then innovation decreases marginal costs but increases fixed costs. Therefore, R&D investment is incorporated in the model through the marginal and firm-specific fixed costs. In fact, we have that C and Γ are respectively:

$$C = (c - \theta k) \quad (5)$$

$$\Gamma = \gamma \frac{k^2}{2} + f \quad (6)$$

Where k is R&D investment conducted by the home firm (and similarly k^* for the foreign firm), θ is a parameter that indicates the cost-reducing effect of R&D investment (with $\theta = \theta^*$), and γ is another parameter that measures the cost of R&D investment (with $\gamma = \gamma^*$)⁸. Besides, c and f are respectively the marginal and the firm-specific fixed costs without R&D investment, with $c = c^*$ and also $f = f^*$.

As such, R&D investment has two main characteristics: it reduces marginal costs through θ (that is why this type of R&D investment is also called cost-reducing); but increases fixed costs through γ . The net effect on the competitiveness and profitability of a firm depends therefore on the relation between θ and γ , since the first increases the competitiveness, while the second reduces profitability. Another way to interpret this is to say that when γ is high, R&D

⁶Note that, x is exports if the home firm is domestic, but is direct sales in the foreign market when the home firm is multinational (and the same for x^*).

⁷This is assumed in order to guarantee that the consumption of the traditional good is always positive in equilibrium.

⁸Also, given that we only assume one factor of production, wages in both sectors (*IRS* and *CRS*) are normalized to one. This is the same assumption as in Horstmann and Markusen (1992).

investment is costly, since it increases considerably firm-specific fixed costs (and the contrary for low γ). By the same token, when θ is high, R&D is said to be very efficient, since it greatly reduces marginal costs (and the contrary for low θ).

Then, like in Petit and Sanna-Randaccio (2000) we also consider process R&D in a multinational model. However, contrary to them, for simplification purposes we do not allow for the existence of technological spillovers⁹. Not including R&D spillovers can be justified if we consider only intangible knowledge based assets such as management, human capital, patents, trademarks, know-how and reputation embodied in non-physical assets that are hard to copy by competitors. Bellow, we argue that this can be the case in what concerns the central issue analyzed in this paper: asymmetric strategic investment capacities among firms.

As such, the main difference between our model and that of HM is that we model explicitly C and Γ through R&D investment, while in HM both are exogenous and equal for all firms, i.e.: $C = c = c^*$ and $\Gamma = f = f^*$. Then, the HM model is a special case of the R&D duopoly model of this paper, with $\theta = \gamma = 0$, i.e.: the HM model is a standard Cournot duopoly model with constant marginal and firm-specific fixed costs. The implication of making these costs endogenous is that we can have firms with different marginal and firm-specific fixed costs, i.e.: endogenous asymmetric firms. This is particularly important because, firm-specific fixed costs intend to represent knowledge-based assets, such as R&D investment, developed internally in the firm and which can only be shared inside the firm by all its plants. Therefore, firm-specific fixed costs represent a strategic aspect of a firm strategy that in our opinion, like all strategic dimensions, must preferably be made endogenous. Also, most likely, firms will desire to have asymmetric strategies, because only this will allow them to be more competitive than rivals. As such, it can prove useful to find ways that permit this to be the case. Bellow we will explain how asymmetries can arise endogenously in the context of the R&D duopoly model.

Two additional notes on the type of R&D investment considered above. In the first place, the quadratic form of the firm-specific fixed costs (equation 6) indicates the possibility of diminishing returns to R&D. This is assumed to assure that firms do not invest in R&D in order to make marginal costs negative. Second, we can enquire if process R&D is the more appropriate mode to model innovation in the context of the issues approached in this paper. For example product innovation R&D can be thought of as a more suitable candidate¹⁰. However, process R&D is an important form of R&D competition, as it is product innovation. In fact, for a firm process R&D can take the form of such different cost-reducing activities as building up information technology, establishing

⁹Note that technological spillovers can be easily introduced in to our model by adding a spillover parameter β , where $\beta \in [0, 1]$. In this case marginal costs of the home firm would be: $C = c - \theta k - \beta k^*$. And similarly for the foreign firm.

¹⁰Product innovation in a Cournot setting can be modeled as in de Bondt et al. (1988) or Veugelers and Vanden Houte (1990), where R&D investment shifts upwards the intercept of demand, for example $P = a(k) - bQ$.

communication channels, promoting the diffusion of knowledge, improving the organization structure, creating innovation systems, introducing software programming for the productive and management routines, as well as developing new production processes. Furthermore, and as argued by Spence (1984) and Tirole (1988) it is not always so simple to distinguish between product and process innovation. According to them, product innovation can generally be regarded as process R&D since, for example, it delivers to consumers what they need at cheaper prices (or inverting the argument, some ‘new’ products are not so new, and the innovation is simply a reduction in the costs of production). Also, a firm new product can lead to a new process in another firm.

We turn now to explain the plant-specific fixed costs (Δ). As mentioned above, the multinational dimension is introduced through Δ . We assume that a firm is domestic if it has only one plant and that it is multinational if it has two plants (i.e.: one plant in each country). More specifically, Δ intends to represent costs related with construction, acquisition and maintenance of every single plant of the firm. Like in HM, we consider the simplest form of these costs where each plant incurs a constant plant-specific fixed cost G , i.e.: a one-plant firm has plant-specific fixed costs of $\Delta = G$, while for a two-plant firm $\Delta = 2G$. Due to this fact, multi-plant economies of scale arise because the total costs of a two-plant firm are $\Gamma + 2G$ and not $2\Gamma + 2G$.

Accordingly we can then have nine different possible market outcomes: none of the firms enters the market, export duopoly, multinational duopoly, multinational *versus* domestic, export monopoly (by the home or by the foreign firm) and multinational monopoly (by the home or by the foreign firm). To simplify matters, the sub-script (i, j) in a variable indicates different market structure configurations; where $i = 0, 1, 2$ is the number of plants operated by the home firm ($i = 0$ if no entry, $i = 1$ if domestic, $i = 2$ if multinational), and $j = 0, 1, 2$ the number of plants operated by the foreign firm. Then we can have the following market structures:

- Case 1, multinational duopoly: (2, 2);
- Case 2, export duopoly: (1, 1);
- Case 3, domestic home firm *versus* multinational foreign firm: (1, 2);
- Case 4, multinational home firm *versus* domestic foreign firm: (2, 1);
- Case 5, multinational monopoly by the home firm: (2, 0);
- Case 6, export monopoly by the home firm: (1, 0);
- Case 7, multinational monopoly by the foreign firm: (0, 2);
- Case 8, export monopoly by the foreign firm: (0, 1);
- Case 9, no-entry by both the home and the foreign firm: (0, 0).

We can now define firms’ profits under a general case that encompasses all possible market structures configurations characterized above:

$$\begin{aligned}\Pi_{i,j} &= (P_{i,j} - C_{i,j})q_{i,j} + (P_{i,j}^* - C_{i,j} - t_i)x_{i,j} - \Gamma_{i,j} - \Delta_i \\ \Pi_{i,j}^* &= (P_{i,j}^* - C_{i,j}^*)q_{i,j}^* + (P_{i,j} - C_{i,j}^* - t_j^*)x_{i,j}^* - \Gamma_{i,j}^* - \Delta_j^*\end{aligned}\quad (7)$$

Where t_i represents trade costs on the *IRS*-good when the home firm has

$i = 1, 2$ plants (the same interpretation for t_j^*)¹¹. Then, we have for the home firm that if $i = 1$, $t_1 = t$ and $\Delta_1 = G$; while for $i = 2$, $t_2 = 0$ (i.e.: products are not subject to trade cost when they are sold in the country where they are produced) and $\Delta_2 = 2G$. Similarly for the foreign firm, if $j = 1$ we have that $t_1^* = t$ and $\Delta_1^* = G$ (i.e.: the home and the foreign firm bear the same trade and plant-specific fixed costs); while for $j = 2$, $t_2^* = 0$ and $\Delta_2^* = 2G$.

In what concerns the timing of the game, we consider three games that differ in the type of R&D investment performed by firms and therefore also in the order of moves by players. In the first game all firms invest strategically, in the second game all firms invest non-strategically, and in the third game the home firm invest strategically while the foreign firm non-strategically. These games are respectively called:

Game A, strategic investment game: *SI*;

Game B, non-strategic investment game: *NSI*;

Game C, home strategic investment game: *HSI*.

The abbreviations (*SI*, *NSI* and *HSI*) will be used in upper-scripts to identify these games. The major difference between these three games is, therefore, different capacities by firms to invest strategically in R&D. As discussed in the introduction, when a firm invests strategically in R&D it commits to the output stage. As a result R&D investment is chosen in a previous stage to the output decision. The contrary happens when R&D investment is non-strategic, and as such outputs and R&D investment are set simultaneously. Then, the *SI* game has three stages but the *NSI* game has only two. More concretely, in the *SI* game, in the first-stage firms make the entering decision: single-plant strategy (domestic firm that is established in one market and exports to the other), two-plant strategy (multinational firm that has a plant in each market), or simply no entry in the market. In the second-stage, firms choose R&D levels. In the third-stage, firms compete in quantities *à la* Cournot. In turn in the *NSI* game, the first stage is as in the *SI* game, but in the second stage firms choose R&D and output levels simultaneously. Finally, in the *HSI* game, the home firm moves as in the *SI* game but the foreign firm moves as in the *NSI* game, i.e.: in the first stage both firms make the entry decision, in the second stage only the home firm moves by choosing R&D levels, and in the third stage while the home firm chooses solely outputs, the foreign firm decides simultaneously on R&D and output levels.

Therefore, when a firm can invest strategically, it can use R&D investment not only to improve its own productive efficiency, but also to affect rivals' performance. When a firm cannot invest strategically, instead, the first holds but the second does not. Then, strategic investment is related with power issues, because only more powerful firms can commit in advance to R&D levels before making their output decisions. Consequently, if a firm that invests strategically competes with another one that cannot invest strategically this can give leader advantages to the former. Then, in result of different abilities to invest strategically, a firm can also become endogenously asymmetric of the rival. This is an

¹¹We assume that the traditional good is freely traded.

interesting property, because firms invest in R&D with the objective of differentiation from competitors. Also, in the context of multinational activity this is very relevant, since these firms are believed to have great capacity to become asymmetric of competitors and possess higher power levels than domestic firms. Additionally, R&D investment is in a particularly relevant position to be used strategically, since innovation affects the competitiveness level of a firm, but also the competitive game against rivals.

These different games can be seen as representing alternative market place competitive realities. In the *SI* game we consider two powerful firms but of equal size and endowments. In the *NSI* game, firms are not so powerful as in the first case, since they cannot invest strategically, but they continue to be of equal size and endowments. In the *HSI* game, the home firm is more powerful than the foreign, since only the former can invest strategically in R&D.

Also, the *HSI* game can be thought of as a kind of Stackelberg quantity leadership model with a previous stage of investment in R&D. However, like in the capacity entry-deterrence models of Spence (1977) and Dixit (1980), we explain from where the first-mover advantage comes and why strategies have a commitment value. Namely, in our model the leader advantage results from the fact that one firm invests strategically in R&D (while the rival does not); and R&D investment has a commitment value because it is a sunk cost¹². We differ from Spence (1977) and Dixit (1980) in that we do not only discuss the influence of leader advantages on entry and exit of firms but also on the type of entry strategy (export *versus* monopoly) and associated market structure.

We can think of two cases where a firm can have more capacity to invest strategically in R&D than rivals. The first case is when firms are from countries in different stages of development. The firm that can invest strategically belongs to a developed country while the other belongs to a developing economy. Conversely, developed countries firms are more technologically advanced than firms from developing countries, and as such the former have more capacity to invest strategically than the later. The second case is more general and can encompass even firms from the same country: different capacities to invest strategically in R&D can arise because some firms are more powerful than others as a result of firm-specific assets such as organizational capability, financial resources, patents, research history, reputation, human resources and so on. Then when a firm has more capacity to invest strategically it is more difficult for R&D spillovers to arise: in the first case because the firm from the developing country may have no capacity to seize foreign knowledge, and in the second case since the type of assets referred are more difficult to imitate and copy by rivals. As such, we believe that in the *HSI* game, the no-spillovers assumption can be justified. This is not easily the case for the other games (*SI* and *NSI*), however, to facilitate the comparison between the three games we maintain the same premise of no-spillovers in all of them. The formal implication of these different games for the R&D model will be made clear in the following sections.

¹²In Spence (1977) and Dixit (1980) the first-mover advantage comes from investment in capacity, that also have a commitment value because it is sunk.

In resume, like in HM, we analyze the mode of foreign expansion by firms, but as in Petit and Sanna-Randaccio (2000) we introduce R&D investment to see the interconnections between the two phenomena. Our model, however, differs from Petit and Sanna-Randaccio (2000) in that we consider the effects of different abilities to invest strategically in R&D on the incentives to innovate and the mode of foreign expansion.

3 Solving the Model

The multinational model is solved in the usual fashion by backward induction. However, in spite of considering three games that differ in the order of the moves of the players, they can be solved in a similar way in what concerns the production variables (R&D and outputs). As such the strategy we are going to follow in this section is to find the general R&D and output expressions common to the three games, and only in the next one to present the explicit equations. Instead, the solution of the entry game is only going to be worked out in a subsequent section.

3.1 Outputs

The output expressions are found by using the FOCs in relation to q , x , q^* and x^* : $d\Pi/dq = 0$, $d\Pi/dx = 0$, $d\Pi/dq^* = 0$ and $d\Pi/dx^* = 0$. Outputs are then maximized taken as given R&D investment levels and entry strategies. As a result, at this phase of computation output levels are independent of the type of game considered (i.e.: if firms can or cannot strategically invest in R&D). Outputs will only depend on the type of game considered after substituting for the R&D investment expressions. Having said this, we can define output levels under all market structure configurations. We start with the multinational duopoly case where we have¹³:

$$\begin{aligned} q_{2,2} &= x_{2,2} = \frac{D+2\theta k-\theta k^*}{3b} \\ q_{2,2}^* &= x_{2,2}^* = \frac{D+2\theta k^*-\theta k}{3b} \end{aligned} \quad (8)$$

Where $D = (a - c)$ is a measure of market size, since it represents the maximum profit margin possible in a good without R&D investment. We assume that at least $D > t > 0$, in order to assure that market size always pays for trade costs. Note however that this condition does not guarantee *per se* that trade is possible. Below we will derive conditions to rule out autarchy scenarios that, as we shall see, also satisfy $D > t$.

In the exporting duopoly case output levels are:

¹³As mentioned before, each market structure is indicated by a sub-script. Then, for example $q_{2,2}$ refers to the home firm domestic output under the multinational duopoly case.

$$\begin{aligned}
q_{1,1} &= \frac{D+t+2\theta k-\theta k^*}{3b} \\
x_{1,1} &= \frac{D-2t+2\theta k-\theta k^*}{3b} \\
q_{1,1}^* &= \frac{D+t+2\theta k^*-\theta k}{3b} \\
x_{1,1}^* &= \frac{D-2t+2\theta k^*-\theta k}{3b}
\end{aligned} \tag{9}$$

Instead, in the home domestic *versus* foreign multinational case, only the home firm incurs trade costs. Then we have that: $q_{1,2} = q_{2,2}$, $x_{1,2} = x_{1,1}$, $q_{1,2}^* = q_{1,1}^*$ and $x_{1,2}^* = q_{2,2}^*$. In turn, the home multinational *versus* foreign domestic case is symmetric to the previous case and as such: $q_{2,1} = q_{1,1}$, $x_{2,1} = x_{2,2}$, $q_{2,1}^* = q_{2,2}^*$ and $x_{2,1}^* = x_{1,1}^*$.

For the home multinational monopoly case, domestic sales equal sales in the foreign market:

$$q_{2,0} = x_{2,0} = \frac{D+\theta k}{2b} \tag{10}$$

In the home exporting monopoly case, local sales are as in the home multinational monopoly case, i.e.: $q_{1,0} = q_{2,0}$. However, since the home firm incurs trade costs to export to the foreign country, foreign sales equal:

$$x_{1,0} = \frac{D-t+\theta k}{2b} \tag{11}$$

The foreign multinational and exporting monopoly market structures are, respectively, symmetric to the home multinational and the exporting monopoly cases. Therefore, $q_{0,2}^* = x_{0,2}^* = q_{2,0}$; and $q_{0,1}^* = q_{1,0}$ and $x_{0,1}^* = x_{1,0}$.

Finally note that, as expected, under all market structures a firm output increases with own R&D investment but decreases with R&D investment performed by the rival.

3.2 R&D Investment

R&D expressions are found by using the FOCs in relation to k and k^* . However, contrary to outputs, to solve for R&D investment we have to take into consideration whether firms can strategically invest or not. To see this, it may be helpful to write the FOC in relation to R&D investment in a way that encompasses both the strategic investment and no-strategic investment cases. For the home firm this is¹⁴:

$$\frac{d\Pi}{dk} = \frac{\partial\Pi}{\partial k} + \frac{\partial\Pi}{\partial q^*} \frac{dq^*}{dk} + \frac{\partial\Pi}{\partial x^*} \frac{dx^*}{dk} \tag{12}$$

$$s.t. \quad : \quad c - \theta k \geq 0 \text{ and } k \geq 0 \tag{13}$$

¹⁴Note that, the whole FOC in relation to k is: $\frac{\partial\Pi}{\partial k} + \frac{\partial\Pi}{\partial q} \frac{dq}{dk} + \frac{\partial\Pi}{\partial x} \frac{dx}{dk} + \frac{\partial\Pi}{\partial q^*} \frac{dq^*}{dk} + \frac{\partial\Pi}{\partial x^*} \frac{dx^*}{dk} = 0$. However, from the envelop theorem (i.e.: the FOC for outputs) $\frac{\partial\Pi}{\partial q} = \frac{\partial\Pi}{\partial x} = 0$, and as such these terms cancel-out.

A similar FOC applies for the foreign firm. First note that we impose restrictions such that marginal costs and R&D investment levels are non-negative. Second, the first term in the expression $(\partial\Pi/\partial k)$ is the so-called non-strategic motive of R&D investment, while the second and third terms $(\frac{\partial\Pi}{\partial q^*} \frac{dq^*}{dk}$ and $\frac{\partial\Pi}{\partial x^*} \frac{dx^*}{dk}$) are the strategic motives. Conversely, R&D is said to be non-strategic if the second and third terms are zero. This happens for example when a firm chooses R&D and outputs simultaneously, as in the *NSI* game. On the contrary, R&D is strategic when the second and third terms are non-negative. This is the case when firms choose R&D in a previous stage to outputs.

Then, in the *SI* game both the home and the foreign firm consider the three terms in the FOC when choosing R&D investment levels; in the *NSI* game both the home and the foreign firm only realize the first term; while in the *HSI* game, the home firm takes into account the three terms while the foreign firm only the first. We turn now to each of these games.

The first thing to note is that in the monopoly cases $((2, 0), (1, 0), (0, 2)$ and $(0, 1))$ under all games considered (*SI*, *NSI* and *HSI*), a monopolist invests in R&D ignoring the strategic terms of equation 12 (the second and third terms). Then, R&D investment levels equal (see appendix for proof):

$$\begin{aligned} k_{i,0} &= \frac{\theta}{\gamma} (q_{i,0} + x_{i,0}), \\ k_{0,j}^* &= \frac{\theta}{\gamma} (q_{0,j}^* + x_{0,j}^*), \text{ for } \forall \text{ games and } i, j = 1, 2. \end{aligned} \quad (14)$$

This is obviously so, given that a monopolist has no rivals, and therefore the second and third terms cancel out. Conversely, the monopolist has no incentives to strategically invest in R&D, because it does not need to affect the strategic choices of anyone.

The same does not happen in the duopoly cases $((2, 2), (1, 1), (1, 2)$ and $(2, 1))$, where R&D investment depends on the type of game considered. In the *SI* game, both the home and the foreign firm invest strategically in R&D, and as such we have (see appendix):

$$\begin{aligned} k_{i,j}^{SI} &= \frac{4\theta}{3\gamma} (q_{i,j}^{SI} + x_{i,j}^{SI}), \\ k_{i,j}^{*SI} &= \frac{4\theta}{3\gamma} (q_{i,j}^{*SI} + x_{i,j}^{*SI}), \text{ for } i, j \neq 0. \end{aligned} \quad (15)$$

In the *NSI* game none of the firms invests strategically and therefore, similarly to the monopoly cases we get (see appendix):

$$\begin{aligned} k_{i,j}^{NSI} &= \frac{\theta}{\gamma} (q_{i,j}^{NSI} + x_{i,j}^{NSI}), \\ k_{i,j}^{*NSI} &= \frac{\theta}{\gamma} (q_{i,j}^{*NSI} + x_{i,j}^{*NSI}), \text{ for } i, j \neq 0. \end{aligned} \quad (16)$$

We can then see that in the *SI* game firms over-invest by a proportion of $4/3$ relatively to the *NSI* game. This is in accordance with the Fudenberg and Tirole (1984) results. They show that a Cournot duopolist over-invests in R&D

to discourage entry by the rival. This happens to be so because in Cournot competition outputs are strategic substitutes (see Bulow *et al.* 1985)¹⁵, i.e.: if q^* and x^* increase, q and x decrease (and consequently also home profits). But since if k increases, q^* and x^* decrease, then $\frac{\partial \Pi}{\partial q^*} \frac{dq^*}{dk} = \frac{\theta}{3}x > 0$ and $\frac{\partial \Pi}{\partial x^*} \frac{dx^*}{dk} = \frac{\theta}{3}q > 0$, i.e.: the strategic effect is positive and, therefore, a Cournot duopolist over-invests in R&D.

In the *HSI* game, only the home firm can invest strategically in R&D. Then, the home firm invests strategically in R&D like in the *SI* game, while the foreign firm invests non-strategically, as in the *NSI* game (see appendix):

$$\begin{aligned} k_{i,j}^{HSI} &= \frac{4\theta}{3\gamma} (q_{i,j}^{HSI} + x_{i,j}^{HSI}), \\ k_{i,j}^{*HSI} &= \frac{\theta}{\gamma} (q_{i,j}^{*HSI} + x_{i,j}^{*HSI}), \text{ for } i, j \neq 0. \end{aligned} \quad (17)$$

Now we can solve explicitly for outputs and R&D investment levels under all games and market structures considered.

4 Outputs and R&D Investment Expressions

In this section we show the explicit R&D and output expressions for the *SI*, *NSI* and *HSI* games.

4.1 Strategic Investment Game

In the *SI* game firms are symmetric in the capacity to invest strategically. This implies that in the multinational duopoly case, since entry strategies are also symmetric, outputs and R&D investment levels by the home and the foreign firms are equal¹⁶:

$$\begin{aligned} q_{2,2} &= x_{2,2} = q_{2,2}^* = x_{2,2}^* = 3\gamma \frac{D}{9b\gamma - 8\theta^2} \\ k_{2,2} &= k_{2,2}^* = \frac{8\theta D}{9b\gamma - 8\theta^2} \end{aligned} \quad (18)$$

In the exporting duopoly case, also due to symmetric entry strategies, the home and the foreign firm produce and invest the same. However due to trade costs domestic sales differ from exports:

$$\begin{aligned} q_{1,1} &= q_{1,1}^* = \frac{3\gamma b D + t(3\gamma b - 4\theta^2)}{b(9b\gamma - 8\theta^2)} \\ x_{1,1} &= x_{1,1}^* = \frac{3\gamma b D - t(6\gamma b - 4\theta^2)}{b(9b\gamma - 8\theta^2)} \\ k_{1,1} &= k_{1,1}^* = \frac{4\theta}{9b\gamma - 8\theta^2} (2D - t) \end{aligned} \quad (19)$$

¹⁵If Bertrand competition the opposite occurs, i.e.: a firm under-invests in R&D since prices are strategic complements. The rationale in this case is that under-investment softens price competition.

¹⁶In order not to burden the notation, in this subsection we omit the upper-script for *SI* game.

The same no longer happens in the home domestic *versus* foreign multinational case, since entry strategies are asymmetric. Consequently, home and foreign outputs and R&D investment levels differ. Make $\varphi = (27b^2\gamma^2 - 32\theta^2(3b\gamma - 2\theta^2))$ to obtain:

$$\begin{aligned}
q_{1,2} &= \frac{1}{3b\varphi} (9b\gamma D (3b\gamma - 8\theta^2) - 4t\theta^2 (15b\gamma - 16\theta^2)) \\
x_{1,2} &= \frac{1}{3b\varphi} (9b\gamma D (3b\gamma - 8\theta^2) - t (6b\gamma (9b\gamma - 22\theta^2) + 64\theta^4)) \\
q_{1,2}^* &= \frac{1}{3b\varphi} (9Db\gamma (3b\gamma - 8\theta^2) + t (3b\gamma (9b\gamma - 16\theta^2) + 32\theta^4)) \\
x_{1,2}^* &= \frac{1}{3b\varphi} (9Db\gamma (3b\gamma - 8\theta^2) + 16t\theta^2 (3b\gamma - 2\theta^2)) \\
k_{1,2} &= \frac{8\theta}{\varphi} (D (3b\gamma - 8\theta^2) - t (3b\gamma - 4\theta^2)) \\
k_{1,2}^* &= \frac{8\theta}{\varphi} (2D (3b\gamma - 8\theta^2) + 3tb\gamma)
\end{aligned} \tag{20}$$

Note that this differs from HM. In fact in the HM model, outputs under the (2, 1) market structure equal outputs from the (2, 2) and (1, 1) cases, i.e.: $q_{1,2}^{HM} = x_{1,2}^{HM} = q_{2,2}^{HM}$, $x_{1,2}^{HM} = x_{1,1}^{HM}$ and $q_{1,2}^{*HM} = q_{1,1}^{*HM}$. Such does not happen in the *SI* game due to R&D investment that together with asymmetric entry strategies gives the multinational firm the chance to become asymmetric of the domestic firm¹⁷.

In turn, the home multinational *versus* foreign domestic market structure is symmetric to the home domestic *versus* foreign multinational, given that strategies are symmetric in the two cases. then: $x_{2,1} = x_{1,2}^*$, $q_{2,1} = q_{1,2}^*$, $x_{2,1}^* = x_{1,2}$, $q_{2,1}^* = q_{1,2}$, $k_{2,1} = k_{1,2}^*$ and $k_{2,1}^* = k_{1,2}$.

In the home multinational monopoly case, the resulting expressions for outputs and R&D investment levels are:

$$\begin{aligned}
q_{2,0} &= x_{2,0} = \frac{\gamma D}{2(b\gamma - \theta^2)} \\
k_{2,0} &= \frac{\theta D}{b\gamma - \theta^2}
\end{aligned} \tag{21}$$

Passing now on to the exporting monopoly case, outputs and R&D investment equal:

$$\begin{aligned}
q_{1,0} &= \frac{2b\gamma D - \theta^2 t}{4b(b\gamma - \theta^2)} \\
x_{1,0} &= \frac{2b\gamma D - t(2b\gamma - \theta^2)}{4b(b\gamma - \theta^2)} \\
k_{1,0} &= \frac{\theta(2D - t)}{2(b\gamma - \theta^2)}
\end{aligned} \tag{22}$$

The foreign multinational and the exporting monopoly market structures are symmetric, respectively, to the home multinational and exporting monopoly

¹⁷As we shall see bellow, the same occurs under the *NSI* and the *HSI* games.

cases. As such we have that $q_{0,2}^* = x_{0,2}^* = q_{2,0} = x_{2,0}$ and $k_{0,2}^* = k_{2,0}$; and $q_{0,1}^* = q_{1,0}$, $x_{0,1}^* = x_{1,0}$ and $k_{0,1}^* = k_{1,0}$.

In addition, we impose two stability conditions. The first is that under all market structure configurations R&D investment is always positive. It can be easily checked that, as long as $D > t$, this is so if:

$$\gamma > \frac{8}{3} \frac{\theta^2}{b} \quad (23)$$

We call this the R&D condition. Equation 23 also guarantees that $\varphi > 0$ and that the second-order condition (SOC) is satisfied (see appendix)¹⁸.

The second stability condition considers parameter values such that trade is possible under all market structure configurations. We want to eliminate the possibility of autarchy scenarios because these are highly unrealistic in today's world economy. For this to be verified we just need to impose that $x_{1,2}$ or $x_{2,1}^*$ (since $x_{1,2} = x_{2,1}^*$) are positive, given that the multinational *versus* exporter is the most disadvantageous market structure case for an exporting firm: not only the exporting firm incurs trade costs to serve the rival domestic market but also faces competition from a multinational firm. Then making $x_{1,2} = 0$ and solving for D we obtain:

$$D > \frac{2}{9} t \frac{3(9b\gamma - 22\theta^2)b\gamma + 32\theta^4}{b\gamma(3b\gamma - 8\theta^2)} \quad (24)$$

We call this condition the overlapping market condition (*OMC*). Equation 24 defines the threshold level of market size in relation to trade costs, cost-reducing effect of R&D and cost of R&D that makes trade profitable in a duopolist industry. Note further that equation 24 is also sufficient to guarantee that $D > t$.

Summing up, as long as equations 23 and 24 are satisfied, then, under all market structure configurations of the *SI* game trade is possible and firms perform positive R&D investment levels.

4.2 Non-Strategic Investment Game

We look now to the *NSI* game where all firms invest non-strategically. Then in the *NSI* game, as in the *SI* game, firms are symmetric in their capacity to strategically invest.

We start with the multinational duopoly market structure. Due to symmetric entry strategies, as in the *SI* game, outputs and R&D investment levels under this case are equal for both the home and the foreign firm¹⁹:

$$\begin{aligned} q_{2,2} &= x_{2,2} = q_{2,2}^* = x_{2,2}^* = \gamma \frac{D}{3b\gamma - 2\theta^2} \\ k_{2,2} &= k_{2,2}^* = 2\theta \frac{D}{3b\gamma - 2\theta^2} \end{aligned} \quad (25)$$

¹⁸The SOC for all the strategic investment games of this chapter (*SI*, *NSI* and *HSI*) is: $9\gamma b - 16\theta^2 < 0$. Note also, that the R&D condition in our model ($\varphi > 0$) is the same as in Petit and Sanna-Randaccio (2000) considering the case of no-spillovers.

¹⁹In order not to burden the notation, in this sub-section we omit the upper-script for *NSI* game.

The same happens under the exporting duopoly market structure, given that also in this case, entry strategies are symmetric:

$$\begin{aligned}
q_{1,1} &= q_{1,1}^* = \frac{Db\gamma + t(b\gamma - \theta^2)}{(3b\gamma - 2\theta^2)b} \\
x_{1,1} &= x_{1,1}^* = \frac{Db\gamma - t(2b\gamma - \theta^2)}{(3b\gamma - 2\theta^2)b} \\
k_{1,1} &= k_{1,1}^* = \theta \frac{2D - t}{3b\gamma - 2\theta^2}
\end{aligned} \tag{26}$$

In the home domestic *versus* foreign multinational market structure, firms have different entry strategies and as such there is no equivalence between outputs and R&D investment levels by the home and the foreign firm. Making $\varphi' = (3b^2\gamma^2 - 4\theta^2(2b\gamma - \theta^2))$, we have:

$$\begin{aligned}
q_{1,2} &= \frac{1}{3b\varphi'} (3Db\gamma(b\gamma - 2\theta^2) - t\theta^2(5b\gamma - 4\theta^2)) \\
x_{1,2} &= \frac{1}{3b\varphi'} (3Db\gamma(b\gamma - 2\theta^2) - t(b\gamma(6b\gamma - 11\theta^2) + 4\theta^4)) \\
q_{1,2}^* &= \frac{1}{3b\varphi'} (3Db\gamma(b\gamma - 2\theta^2) + t(b\gamma(3b\gamma - 4\theta^2) + 2\theta^4)) \\
x_{1,2}^* &= \frac{1}{3b\varphi'} (3Db\gamma(b\gamma - 2\theta^2) + 2t\theta^2(2b\gamma - \theta^2)) \\
k_{1,2} &= \frac{2\theta}{\varphi'} (D(b\gamma - 2\theta^2) - t(b\gamma - \theta^2)) \\
k_{1,2}^* &= \frac{\theta}{\varphi'} (2D(b\gamma - 2\theta^2) + tb\gamma)
\end{aligned} \tag{27}$$

Again, as in the *SI* game, the home multinational *versus* foreign domestic case is symmetric to the previous case. Therefore: $q_{2,1} = q_{1,2}^*$, $x_{2,1} = x_{1,2}^*$, $q_{2,1}^* = q_{1,2}$, $x_{2,1}^* = x_{1,2}$, $k_{2,1} = k_{1,2}^*$ and $k_{2,1}^* = k_{1,2}$.

Also, as we have said before, since in the monopoly cases ((2,0), (1,0), (0,2) and (0,1)) firms invest non-strategically, then these market structure cases always have the same solution independently of the type of strategic investment game considered. Therefore, output and R&D investment expressions of the monopoly cases under the *NSI* game are the same as in the previous *SI* game (i.e.: equations 21 and 22).

Furthermore, like in the *SI* game, we also impose two stability conditions in the *NSI* game. The first condition assures that firms perform positive R&D investment levels under all market structure configurations. As long as $D > t$, this is so if:

$$\gamma > \frac{2}{b}\theta^2 \tag{28}$$

The R&D condition for the *NSI* game also guarantees that $\varphi' > 0$ and that the SOC is satisfied (see appendix). The second condition intends to assure that trade is always possible, therefore eliminating autarchy scenarios. As before the *OMC* is found by making $x_{1,2} = 0$ (or $x_{2,1}^* = 0$) and solving for D , to obtain:

$$D > \frac{1}{3}t \frac{(6b\gamma - 11\theta^2)b\gamma + 4\theta^4}{b\gamma(b\gamma - 2\theta^2)} \tag{29}$$

The *OMC* of the *NSI* game is also sufficient to guarantee that $D > t$.

4.3 Home Strategic Investment Game

In the *HSI* game only the home firm can invest strategically. Then, what differentiates the *HSI* game from the previous ones (*SI* and *NSI* games) is that the home and the foreign firm have asymmetric capacities to invest strategically in R&D.

In the multinational duopoly case, in spite of firms having symmetric entry strategies, asymmetries on the ability to invest strategically lead to that contrary to previous games, only $q_{2,2} = x_{2,2}$, and $q_{2,2}^* = x_{2,2}^*$, but $q_{2,2} = x_{2,2} \neq q_{2,2}^* = x_{2,2}^*$ and also $k_{2,2} \neq k_{2,2}^*$ ²⁰. Making $\varphi'' = (9b^2\gamma^2 - 4\theta^2(7b\gamma - 4\theta^2))$, we obtain:

$$\begin{aligned}
q_{2,2} &= x_{2,2} = 3D(b\gamma - 2\theta^2) \frac{\gamma}{\varphi''} \\
q_{2,2}^* &= x_{2,2}^* = D\gamma \frac{3b\gamma - 8\theta^2}{\varphi''} \\
k_{2,2} &= 8D\theta \frac{b\gamma - 2\theta^2}{\varphi''} \\
k_{2,2}^* &= 2D\theta \frac{3b\gamma - 8\theta^2}{\varphi''}
\end{aligned} \tag{30}$$

In the exporting duopoly case entry strategies continue to be symmetric. However, since strategic investment capacity is asymmetric, contrary to the *SI* and the *NSI* games, the home and the foreign firm no longer have equal output and R&D levels (i.e.: $q_{1,1} \neq q_{1,1}^*$, $x_{1,1} \neq x_{1,1}^*$ and also $k_{1,1} \neq k_{1,1}^*$):

$$\begin{aligned}
q_{1,1} &= \frac{3Db\gamma(b\gamma - 2\theta^2) + t(b\gamma(3b\gamma - 11\theta^2) + 8\theta^4)}{b\varphi''} \\
x_{1,1} &= \frac{3Db\gamma(b\gamma - 2\theta^2) - t(b\gamma(6b\gamma - 17\theta^2) + 8\theta^4)}{b\varphi''} \\
q_{1,1}^* &= \frac{Db\gamma(3b\gamma - 8\theta^2) + t(b\gamma(3b\gamma - 10\theta^2) + 8\theta^4)}{b\varphi''} \\
x_{1,1}^* &= \frac{Db\gamma(3b\gamma - 8\theta^2) - t(2b\gamma(3b\gamma - 9\theta^2) + 8\theta^4)}{b\varphi''} \\
k_{1,1} &= 4\theta(b\gamma - 2\theta^2) \frac{2D-t}{\varphi''} \\
k_{1,1}^* &= \theta(3b\gamma - 8\theta^2) \frac{2D-t}{\varphi''}
\end{aligned} \tag{31}$$

In the home domestic *versus* foreign multinational case, we have two levels of asymmetries: entry strategies and strategic investment. This results in the following output and R&D investment levels:

²⁰In order not to burden the notation, in this subsection we omit the upper-script for *HSI* game.

$$\begin{aligned}
q_{1,2} &= \frac{9Db\gamma(b\gamma-2\theta^2)-t\theta^2(19b\gamma-16\theta^2)}{3b\varphi''} \\
x_{1,2} &= \frac{9Db\gamma(b\gamma-2\theta^2)-t(b\gamma(18b\gamma-37\theta^2)+16\theta^4)}{3b\varphi''} \\
q_{1,2}^* &= \frac{Db\gamma(9b\gamma-24\theta^2)+t(b\gamma(9b\gamma-14\theta^2)+8\theta^4)}{3b\varphi''} \\
x_{1,2}^* &= \frac{Db\gamma(9b\gamma-24\theta^2)+2t\theta^2(7b\gamma-4\theta^2)}{3b\varphi''} \\
k_{1,2} &= 8\theta \frac{D(b\gamma-2\theta^2)-t(b\gamma-\theta^2)}{\varphi''} \\
k_{1,2}^* &= \theta \frac{2D(3b\gamma-8\theta^2)+3b\gamma t}{\varphi''} \tag{32}
\end{aligned}$$

In contrast to the previous games, under the *HSI* game the home multinational *versus* foreign domestic case is not symmetric to the home domestic *versus* foreign multinational case. This is so, because the home and the foreign firm have different capacities to invest strategically in R&D, regardless of the fact that in these two market structures they have symmetric entry strategies. In fact, in the (1, 2) market structure, the multinational foreign firm cannot invest strategically but the domestic home firm can; instead in the (2, 1) market structure, the multinational home firm can invest strategically, but the opposite is the case for the domestic foreign firm. As a result, outputs and R&D investment levels under these two cases are not symmetric. In concrete, the explicit expressions for the (2, 1) market structure are:

$$\begin{aligned}
q_{2,1} &= \frac{9b\gamma D(b\gamma-2\theta^2)+t(b\gamma(9b\gamma-14\theta^2)+8\theta^4)}{3b\varphi''} \\
x_{2,1} &= \frac{9b\gamma D(b\gamma-2\theta^2)+2\theta^2 t(7b\gamma-4\theta^2)}{3b\varphi''} \\
q_{2,1}^* &= \frac{3Db\gamma(3b\gamma-8\theta^2)-16t\theta^2(b\gamma-\theta^2)}{3b\varphi''} \\
x_{2,1}^* &= \frac{3Db\gamma(3b\gamma-8\theta^2)-2t(b\gamma(9b\gamma-20\theta^2)+8\theta^4)}{3b\varphi''} \\
k_{2,1} &= 4\theta \frac{2D(b\gamma-2\theta^2)+b\gamma t}{\varphi''} \\
k_{2,1}^* &= 2\theta \frac{D(3b\gamma-8\theta^2)-t(3b\gamma-4\theta^2)}{\varphi''} \tag{33}
\end{aligned}$$

As mentioned before, the monopoly cases have the same solution independently of the type of the game considered. Therefore, outputs and R&D investment expressions under the monopoly cases of the *HSI* game are the same as in the *SI* and the *NSI* games (i.e.: equations 21 and 22).

Also as in the previous games, we impose two restrictions to the parameter space where the game is valid. The first stability condition assures that firms perform positive R&D investment levels under the different market structures considered. Provided that $D > t$, it can be easily checked that a sufficient condition for this to happen is:

$$\gamma > \frac{8}{3} \frac{\theta^2}{b} \quad (34)$$

The R&D condition also implies that $\varphi'' > 0$ and that the SOC is satisfied (see appendix). The second stability condition imposes that trade is possible for all firms under the different market structures configurations. This is obtained by making $x_{2,1}^* = 0$ and solving for D :

$$D > \frac{2}{3} t \frac{(9b\gamma - 20\theta^2)b\gamma + 8\theta^4}{b\gamma(3b\gamma - 8\theta^2)} \quad (35)$$

The *OMC* for the *HSI* game is found in relation to $x_{2,1}^*$, because it is under this market structure that an exporting firm is more penalized. In fact, not only does the exporting firm competes with a multinational firm, but it also faces a competitor with higher capacity to invest strategically in R&D. Also, the *OMC* of the *HSI* game is also sufficient to guarantee that $D > t$.

5 Comparative Static Results

In this section we analyze some of the comparative static properties of the three strategic investment games: *SI*, *NSI* and *HSI*. We shall see that both the *SI* and the *NSI* games show similar results, however the same does not happen with the *HSI* game.

5.1 Strategic Investment Game

The first result from the *SI* game that we want to highlight is that (see proof in appendix):

$$k_{1,2} < k_{1,2}^* \quad (36)$$

And by symmetry $k_{2,1}^* < k_{2,1}$. This means that when a multinational firm competes with a domestic firm, the former performs more R&D than the latter. Conversely, the multinational firm takes advantage of size effects to invest more in R&D in order to be more competitive than the domestic firm. Furthermore, the multinational firm reaps the benefits of multi-plant economies of scale, since firm-specific fixed costs (i.e.: knowledge) are shared between the two-plants. As a result, not only $q_{1,2} < q_{1,2}^*$ and $x_{1,2} < x_{1,2}^*$, but also (see proof in appendix):

$$q_{1,2} < x_{1,2}^* \quad (37)$$

And by symmetry also $q_{2,1}^* < x_{2,1}$. Then, the multinational firm is more competitive even in the rival domestic market. The advantage of the multinational firm comes from asymmetric entry strategies and R&D investment: the multinational strategy is more powerful than an exporting strategy, and the multinational firm uses this to invest more in R&D than the domestic firm. In other words, the trade-off between lower marginal costs and higher fixed costs

that a firm has to face when it invests in R&D is more easily met by a multinational than by a domestic firm. To see that this results from asymmetric entry strategies, note that under the multinational and exporting duopoly cases ((2, 2) and (1, 1)), where strategies are symmetric, no asymmetry in competitiveness arises. Also, the role of R&D investment is central since this never happens in the no-R&D HM model. In fact, in HM, even in the asymmetric duopoly cases ((1, 2) and (2, 1)) the multinational firm, at most, performs as well as the rival domestic firm, in fact: $q_{1,2}^{HM} = x_{1,2}^{*HM}$. This shows that R&D investment together with asymmetric entry strategies can be a source of endogenous asymmetries between firms.

Proposition 1 *In an international duopolist market where both firms can invest strategically in R&D, endogenous asymmetries between firms can arise as a result of asymmetric entry strategies and R&D investment. When such is the case, the multinational firm invests more in R&D than the exporting firm. The outcome is that the multinational firm is more competitive not only in its own domestic market but also in the rival's market.*

5.2 Non-Strategic Investment Game

In terms of the comparative static implications of the *NSI* game, these are similar to the *SI* game. In fact, as in the *SI* game, in the duopoly asymmetric market structures ((1, 2) and (2, 1)) the multinational firm invests more in R&D than the domestic firm (i.e.: $k_{1,2} < k_{1,2}^*$ and $k_{2,1}^* < k_{2,1}$). Also, as before, not only $q_{1,2} < q_{1,2}^*$ and $x_{1,2} < x_{1,2}^*$, but also $q_{1,2} < x_{1,2}^*$. The reasons for this to be so are the same as those pointed out above for the *SI* game. Then, the result expressed in proposition 1 is independent of strategic investment; what is important is that both firms can invest in R&D and have the same capacity to invest strategically.

Proposition 2 *What determines the result stated above in proposition 1 is not the possibility of firms to strategically invest, but R&D per se. In fact, as long as the duopolists have the same capacity to strategically invest, proposition 1 holds independently whether R&D is strategic or not.*

5.3 Home Strategic Investment Game

In what respects the *HSI* game, we shall see that asymmetries on the capacity to invest strategically have important implications for the R&D model. The first result that we want to emphasize is that, contrary to previous games, the home and the foreign firm always perform different levels of R&D investment (see equations 30 to 33). This is so because the home firm invests strategically, while the foreign firm invests non-strategically. Also the two firms always have different levels of marginal and fixed costs, i.e.: the home and the foreign firm differ in terms of competitiveness. This means that endogenous asymmetries between firms can arise as a result of different abilities to invest strategically in R&D.

Proposition 3 *In an international duopolist market, endogenous productive efficiency asymmetries between firms can arise as a result of different capacities to invest strategically in R&D.*

It remains to know how much of this endogenous asymmetry property affects the comparative efficiency of firms, i.e.: what firm invests more in R&D. As expected, the firm that can invest strategically (i.e.: the home firm) tends to invest more in R&D than the firm that does not invest strategically (i.e.: the foreign firm). This is always the case when entry strategies are symmetric (duopoly cases), but also when the asymmetric entry strategy favors the home firm (i.e.: (2, 1) case):

$$\begin{aligned} k_{2,2} &> k_{2,2}^* \\ k_{1,1} &> k_{1,1}^* \\ k_{2,1} &> k_{2,1}^* \end{aligned} \tag{38}$$

See proof in appendix. Consequently, under the (2, 2), (1, 1) and (2, 1) cases the home firm also produces more than the foreign firm, in fact (see proof in appendix):

$$\begin{aligned} (q_{2,2} + x_{2,2}) &> (q_{2,2}^* + x_{2,2}^*) \\ (q_{1,1} + x_{1,1}) &> (q_{1,1}^* + x_{1,1}^*) \\ (q_{2,1} + x_{2,1}) &> (q_{2,1}^* + x_{2,1}^*) \end{aligned} \tag{39}$$

Besides, there is also the possibility that under the (1, 2) case $k_{1,2} > k_{1,2}^*$. This is so as long as:

$$k_{1,2} > k_{1,2}^*, \text{ if } D > t \frac{11b\gamma - 8\theta^2}{2b\gamma} \tag{40}$$

What this condition says is that the domestic home firm invests more in R&D than the foreign multinational firm if market size (D) is sufficiently big in relation to trade costs (t) and the cost of R&D (γ) is small relatively to the cost-reducing effect of R&D (θ)²¹. Then, a domestic firm that invests strategically in R&D can have an advantage over a multinational firm that does not invest strategically. Note that, this never happens in the *SI* and the *NSI* games, where a domestic firm is always in disadvantage *vis-à-vis* a multinational firm.

Consequently, in the *HSI* game, proposition 1 is only always true for the firm that can invest strategically, i.e.: the home firm. In fact (see proof in appendix) $x_{2,1} > q_{2,1}$, but the same does not happen for $x_{1,2}^*$ in relation to $q_{1,2}$. Only if equation 40 does not hold $x_{1,2}^* > q_{1,2}$, otherwise the contrary happens. Then, the higher capacity to invest strategically can cancel out, at least in part, disadvantages that come from asymmetric entry strategies that domestic firms face with multinational firms.

²¹A similar relation applies for outputs under this market structure case.

This is so, because the performance of a firm depends on two factors: (1) strategic investment; and (2) market structure. Then, since in the (2,2) and in the (1,1) cases, entry strategies are symmetric, the home firm is more competitive because it can invest strategically in R&D against a rival that does not do so. In the (2,1) market structure, the higher competitiveness of the home firm is due to the fact that it has both the advantage of a better entry strategy and higher strategic investment capacity. Finally, in the (1,2) market structure, home has the advantage of strategic investment but it is at a disadvantage in the entry strategy. Then, the home firm is only more competitive than the foreign firm if strategic investment advantages surpass the market structure disadvantage, and otherwise if the contrary happens. Conversely, the trade-off between lower marginal costs and higher fixed costs that a firm faces when it invests in R&D (lower C against higher Γ) is more easily satisfied by more powerful firms: multinationals or firms with higher capacity to invest strategically in R&D.

As a result, if equation 40 is satisfied, the home firm is always at an advantage under all duopoly cases in relation to the foreign firm. This shows that strategic investment can help the home firm even when the prevalent market structure is not favorable (i.e.: (1,2) case). If, on the contrary equation 40 does not hold, the domestic home firm *versus* the foreign multinational firm scenario is not advantageous for the former, since higher capacity in strategic investment is not sufficient *per se* to give the lead of the market. As such, if possible, the home firm will try to prevent this market structure from arising in equilibrium.

In any case (whether equation 40 holds or not), the higher strategic investment capacity of the domestic home firm is disadvantageous to the foreign no-strategic investment multinational firm. In fact, a multinational firm that invests non-strategically and faces a domestic firm that invests strategically ((1,2) case) tends to invest less in R&D than a multinational firm that invests strategically and competes with a domestic firm that cannot do so ((2,1) case):

$$k_{2,1} > k_{1,2}^* \quad (41)$$

See proof in appendix. As a result, under the asymmetric duopoly cases, the strategic investment multinational firm also produces more than the no-strategic investment multinational firm (see proof in appendix):

$$q_{2,1} + x_{2,1} > q_{1,2}^* + x_{1,2}^* \quad (42)$$

This all shows, in the first place, that asymmetries at the level of strategic investment are a strong competitive destabilizing force; and in the second place, that a firm's ability to invest strategically is only important if there are asymmetries at this level (i.e.: if a firm that can invest strategically competes with a firm that cannot invest strategically).

Proposition 4 *In an international duopolist market where firms have different capacities to invest strategically, the firm that invests strategically tends to be more competitive than the firm that does not invest strategically, since the first has a higher propensity to invest more in R&D.*

6 R&D, Strategic Investment and Trade

In this section we look at the effects of innovation and strategic investment on the level of firms' access to international markets. We do this by analyzing the different OMC s of the alternative strategic investment games considered here (SI , NSI and HSI).

The first thing to note is that under all games international trade is promoted for high D and low t . This comes as no surprise, since high market size and low trade costs facilitate trade by making exports more profitable. Secondly, all games (SI , NSI and HSI) show a common behavior in relation to the R&D parameters (θ , and γ). In fact, trade is restricted when the cost-reducing effect of R&D (θ) is very high or the cost of investment (γ) is very low (see proof in appendix):

$$\begin{aligned} \frac{dOMC^{SI}}{d\gamma}, \frac{dOMC^{NSI}}{d\gamma} \text{ and } \frac{dOMC^{HSI}}{d\gamma} &< 0 \\ \frac{dOMC^{SI}}{d\theta}, \frac{dOMC^{NSI}}{d\theta} \text{ and } \frac{dOMC^{HSI}}{d\theta} &> 0 \end{aligned} \quad (43)$$

This is so given that for high θ or low γ , firms are very efficient and competition is very fiercer. As a result exports find it hard to compete with local production. The contrary happens for low θ or high γ . Then, the nature of R&D investment technology can affect international trade patterns.

Proposition 5 *In an international duopolist market, trade is restricted when R&D is very efficient or not too costly, and vice-versa.*

Also, comparing the three alternative games considered in this paper, it can be easily checked (see proof in appendix) that trade is more restricted under the HSI game, followed by the SI game, and then finally by the NSI . In fact:

$$D_{OMC}^{HSI} > D_{OMC}^{SI} > D_{OMC}^{NSI} \quad (44)$$

What this relation says is that the threshold level of market size that makes trade profitable for firms is higher in the HSI game, i.e.: under the HSI game market size needs to be bigger than in the SI and the NSI games for a firm to be able to export. This means that trade is restricted when firms invest strategically in R&D relatively to when they do not do so; and when firms are asymmetric in strategic investment comparatively to when they are symmetric. The rationale for this is that strategic investment and different capacities at this level make competition fiercer. Consequently, trade is made more difficult under these cases, given that firms have more difficulties to penetrate the rival's market.

Proposition 6 *In an international duopolist industry, trade is facilitated when firms do not invest strategically and when firms are symmetric at this level, and vice-versa.*

7 Equilibrium Entry Strategies

In this section we study the equilibrium entry strategies that arise under the different strategic investment games: *SI*, *NSI* and *HSI*. Namely, we find the Nash equilibrium of the entry game between the home and the foreign firm, where payoffs are profits and the strategic space is the number of plants. At this point, it is useful to rewrite the profit expressions defined in equations 7 in the following way:

$$\begin{aligned}\Pi_{i,j} &= b(q_{i,j})^2 + b(x_{i,j})^2 - \Gamma_{i,j} - \Delta_i \\ \Pi_{i,j}^* &= b(q_{i,j}^*)^2 + b(x_{i,j}^*)^2 - \Gamma_{i,j}^* - \Delta_j^*\end{aligned}\quad (45)$$

Note that $P_{i,j} - C_{i,j} = bq_{i,j}$ and $P_{i,j}^* - C_{i,j} - t_i = bx_{i,j}$ come from the FOCs in relation to home outputs (and similarly for the foreign firm). From here it is easy to find simplified profits expressions under the different market structures by substituting only for $q_{i,j}$, $x_{i,j}$, $k_{i,j}$, $q_{i,j}^*$, $x_{i,j}^*$ and $k_{i,j}^*$. However, the complexity involved in some of these profit expressions makes it impossible to find analytical solutions for the game. Instead, we follow HM strategy by using simulation methods to accomplish this task. More precisely, we study the entry choices of firms in the (G, t) space by giving values to the remaining parameters, D , b , γ and θ . By doing this it is possible to identify what market structures prevail for different parameter values.

Before advancing to the R&D game it can be useful to derive the first stage equilibrium of the HM model with homogenous goods. This will allow us to test if HM results are invariant to the homogenous good hypothesis.

Figure 1 then shows the Nash equilibrium outcome of the entry game of the HM model for different combinations of (G, t) . Note that each equilibrium market structure is delimited by isolines. HM explain in detail how these boundaries are generated, and therefore we only give a brief explanation of how these isolines are constructed. In short, the lines showed in the figure 1 are either the difference in profits between alternative market structures (i.e.: $\Pi_{2,2} - \Pi_{1,2}$, $\Pi_{2,1} - \Pi_{1,1}$ and $\Pi_{2,0} - \Pi_{1,0}$) or the loci of profits under a specific market structure (i.e.: $\Pi_{2,2} = 0$, $\Pi_{1,1} = 0$, $\Pi_{1,2} = 0$, $\Pi_{2,0} = 0$ and $\Pi_{1,0} = 0$)²². The boundaries of these expressions delimit the preferences of firms between alternative market structure configurations in the (G, t) space.

Having said this, we can now analyze figure 1 in more detail. The figure is depicted for $D = 16$, $b = 2$ and $f = 17$ ²³. Results can be summarized as follows. For very high plant-specific fixed costs (G), both the home and the foreign firm choose not to enter the market $((0, 0))$. Reducing G a little leads to the exporting monopoly, by either the home or the foreign firm $((1, 0)$ $(0, 1))$. For intermediate

²²Note that in HM: $\Pi_{2,2} - \Pi_{1,2} = \Pi_{2,1} - \Pi_{1,1}$. Also, the $\Pi_{(2,2)}$, $\Pi_{(1,1)}$, $\Pi_{(1,2)}$, $\Pi_{(2,1)}$, $\Pi_{(2,0)}$, $\Pi_{(1,0)}$, $\Pi_{(2,2)} - \Pi_{(1,2)}$ and $\Pi_{(2,0)} - \Pi_{(1,0)}$ curves are represented, respectively, by the following colors: black, blue, brown, cyan, gray, green, magenta and red.

²³The interval of t considered satisfies the *OMC* for the HM model with homogenous goods, namely that $t < D/2$.

values of G but high trade costs (t), the multinational monopoly by either the home or the foreign firm $((2,0) (0,2))$ arises. For intermediate to low G and low t , the exporting duopoly $((1,1))$ is the only equilibrium. However, for low G but medium to high t , the multinational duopoly $((2,2))$ dominates. There is also a region of multiple equilibria where the multinational monopoly and the exporting duopoly market structures coexist $((2,0) (0,2) \text{ and } (1,1))$. This region occurs in the interception of the four equilibria with active firms.

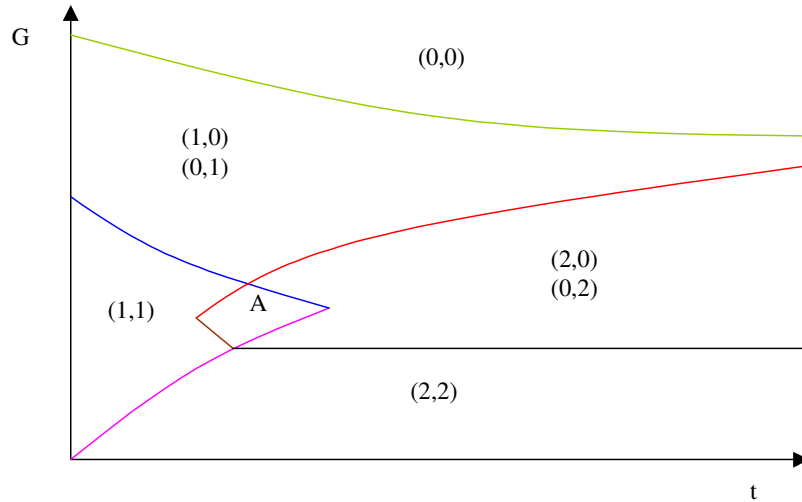


Figure 1: Solution of the entry stage, HM model. A: $(1,1) (2,0) (0,2)$.

Then, low transport cost favors the one-plant strategy, while high t favors the two-plant strategy. In turn, high plant-specific fixed costs support the one-plant strategy, whereas low G support the two-plant strategy. This means that the multinational strategy is preferred for low plant-specific fixed costs and high trade costs (and the contrary for the export strategy).

HM results are therefore obtained under the assumption of homogeneous goods, namely the trade-off between proximity to consumers (multinational strategy to avoid trade costs) and concentration of plants (export strategy to reap the benefits of scale economies). As such, the HM model is not sensitive to the homogeneous goods assumption. More important than that, and as a consequence of this, results from our R&D model can be directly compared with those by HM. We now pass on to analyze the first stage equilibrium of the three strategic investment games studied in this paper. As in previous sections, we start with the *SI* game, then proceed to the *NSI* game and close with the *HSI* game.

7.1 Strategic Investment Game

Figure 2 shows the possible equilibrium market structures of the *SI* game in the (G, t) space. This figure is constructed in the same way as figure 1. However note that now, contrary to the HM model, $\Pi_{2,2} - \Pi_{1,2} \neq \Pi_{2,1} - \Pi_{1,1}$ ²⁴, so that we need to plot these two curves separately²⁵. Further, we restrict the parameter space of analysis to cases where trade is possible and R&D investment is positive. Then we assume that equations 24 (*OMCs*) and 23 (R&D condition) respectively hold. Namely, figure 2 is depicted for $D = 16$, $b = 2$, $\gamma = 45$ and $\theta = 5$ ²⁶, the central case of the *SI* game. In the next section we check robustness to different parameter values.

Results can be summarized as follows. Firms prefer to stay out of the market for very high plant-specific fixed costs (G). For lower but still high G , the exporting monopoly by either the home or the foreign firm $((1, 0) (0, 1))$ arises. In turn, the market structure exporting duopoly $((1, 1))$ dominates for low to intermediate G and low trade costs (t). For intermediate G and intermediate to high t , the multinational monopoly by either the home or the foreign firm $((2, 0) (0, 2))$ emerges. For very low G and intermediate to high t , the multinational duopoly $((2, 2))$ is the only equilibrium. In the diagonal of the (G, t) space and for low G and low t we have the one-plant strategy against a two-plant strategy by either the home or the foreign firm $((2, 1) (1, 2))$. Also in the diagonal, but for intermediate to high G and intermediate to high t there is an area of no-Nash equilibrium.

Comparing figure 2 from the *SI* game with figure 1 from the HM model, we can see that the two pictures are very similar, since under the *SI* game the proximity *versus* concentration trade-off also arises. However, two important differences can be noted. In the first place, a new equilibrium emerges in the *SI* game where a multinational firm shares the market with a one-plant firm. This equilibrium also appears in Markusen and Venables (1998) and in Pontes (2001). However, in Markusen and Venables (1998) it is necessary to assume that countries differ in factor endowments, and in Pontes (2001) that countries have different dimensions. Note that in our model (and also in Petit and Sanna-Randaccio, 2000²⁷), the multinational *versus* domestic case emerges in equilibrium even with symmetric countries in terms of size and endowments. Therefore, what makes this market structure arise here is R&D investment *per se*. In fact, even when countries are symmetric, R&D investment can support asymmetric entry strategies by firms. Then R&D investment can be one of the

²⁴This also happens in the *NSI* and *HSI* games.

²⁵The $\Pi_{(2,2)} - \Pi_{(1,2)}$ and $\Pi_{(2,1)} - \Pi_{(1,1)}$ curves are portrayed respectively by the following colors: magenta and yellow. The other profit curves have the same colors as above for the HM model.

²⁶We set $f = 0$ because firm-specific fixed costs (Γ) are linear in f and therefore changing f only changes the level of the profit curves (i.e.: increasing f reduces profitability and pushes the profit curves down, and *vice-versa*), but do not change the relation between alternative market structures.

²⁷In Petit and Sanna-Randaccio (2000) this equilibrium can also arise but, in contrast to us, they does not show graphically for what parameter space this equilibrium market structure emerges.

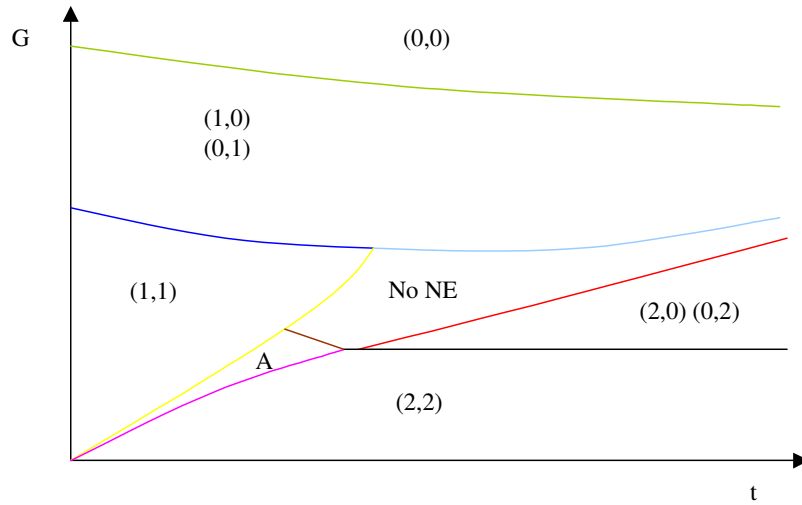


Figure 2: Solution of the entry stage, *SI* game. A: (2, 1) (1, 2).

causes for asymmetric FDI patterns across countries in general, but also in particular in-between countries similar in size and endowments (as some developed countries). Further, this also indicates that R&D investment can allow multinational firms to be able to compete against domestic firms. Such is not possible when firms do not invest in R&D (as in the HM model), since multinational firms have no advantage over domestic firms. As we have seen above, in the R&D model innovative activities allow multi-plant firms to exploit multinationality advantages and become more competitive than domestic firms.

The second difference in relation to the HM model is that in the *SI* game there is a no-Nash equilibrium area. This reveals that when firms invest in R&D, it is more difficult to achieve non-cooperative equilibriums.

7.2 Non-Strategic Investment Game

In this sub-section we solve for the first-stage of the *NSI* game. The central case in the *NSI* game is the same as in the *SI* game. This is done in order to allow us to do a more direct comparison between the two games. Later, we will check the robustness of results of this central case to different parameter and variable values. Once again, we restrict the parameter space of analysis, such that trade is possible and R&D investment is positive. For this to be so, we assume that equations 29 and 28 are satisfied.

The first thing to be noted is that the *NSI* game gives a very similar picture to the one obtained under the *SI* game. For this reason we do not replicate here the *NSI* game picture. This proves our assertion in proposition 2, that the *NSI* and the *SI* games are very similar games, regardless of the fact that in

the first case firms invest in R&D strategically while in the second they invest non-strategically, i.e.: R&D investment has the same effects as long as firms are symmetric in strategic investment. Then, an equivalent to proposition 2 can be the following:

Proposition 7 *In an international duopolist market, if firms are symmetric in strategic investment, R&D investment per se, independently of whether firms can or cannot invest strategically, is sufficient to differentiate the R&D model from a no-R&D model.*

However, some small differences also arise in relation to the *SI* game. First, and as we have seen above, trade in the *NSI* game is promoted. This implies that the horizontal axis area increases, because trade is possible for higher levels of transport costs. Second, the $\Pi_{2,2}$ and the $\Pi_{1,1}$ curves shift up, while the $\Pi_{2,1} - \Pi_{1,1}$ and the $\Pi_{2,1}$ curves shift down. As a result, the monopoly and the no-Nash equilibrium areas are reduced, while the duopoly equilibrium areas are increased²⁸. This is so, due to the fact that in the *NSI* game firms cannot strategically invest in R&D. Consequently, it is also harder for them to force competitors out of the market. This also implies that the indeterminacy in the *NSI* game, as mirrored by the no-Nash equilibrium area, is minimized.

7.3 Home Strategic Investment Game

In this sub-section we present the solution of the first stage of the *HSI* game in the (G, t) space (see figure 3). In order to make a more direct comparison between the *HSI* game and the *SI* and the *NSI* games, the central case of the *HSI* game is the same as above for the other two games. In the next section we will check the robustness of results to this central case. Also, figure 3 is constructed in the same fashion as above, however due to the asymmetry in the game, we now also need to plot some profit curves from the foreign firm, namely: $\Pi_{2,2}^* = 0$, $\Pi_{1,1}^* = 0$, $\Pi_{1,2}^* = 0$, $\Pi_{2,1}^* = 0$, $\Pi_{2,2}^* - \Pi_{2,1}^*$ and $\Pi_{1,2}^* - \Pi_{1,1}^*$ ²⁹. As in previous games, also in the *HSI* game we restrict the parameter space of analysis such that trade is possible and R&D investment is positive for at least one firm. Therefore we impose that equations 35 and 34 are satisfied.

As can be seen from figure 3 the equilibrium of the entry stage under the *HSI* game differs greatly from the *SI* and the *NSI* games. This shows that strategic investment can only have a role in changing equilibrium market structure when firms differ at this level (i.e.: *HSI* game). Otherwise, as we have seen above,

²⁸The $(1, 0)$ $(0, 1)$ equilibrium shrinks, because the $\Pi_{1,1}$ curve shifts up. The $(1, 1)$ equilibrium increases, given that the $\Pi_{1,1}$ curve shifts up and the $\Pi_{2,1} - \Pi_{1,1}$ curve shifts down. The $(2, 0)$ $(0, 2)$ equilibrium shrinks, because the $\Pi_{2,2}$ curve shifts up. The $(2, 2)$ equilibrium increases, since the $\Pi_{2,2}$ curve shifts up and the threshold level of trade costs that makes trade possible increases. The no-Nash equilibrium area is reduced, given that $\Pi_{2,1} - \Pi_{1,1}$ and the $\Pi_{2,1}$ curves shift down.

²⁹Foreign profit curves are represented by dotted lines. Also, $\Pi_{(2,2)}^*$, $\Pi_{(1,1)}^*$, $\Pi_{(1,2)}^*$, $\Pi_{(2,1)}^*$, $\Pi_{(2,2)}^* - \Pi_{(2,1)}^*$ and $\Pi_{(1,2)}^* - \Pi_{(1,1)}^*$ curves are shown respectively with the following colors: black, blue, brown and cyan, magenta and yellow.

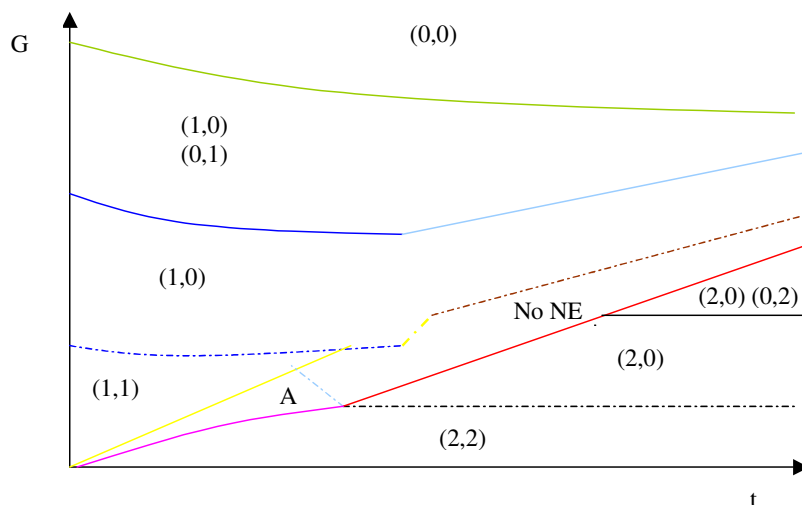


Figure 3: Solution of the entry stage, HC game. A: $(2, 1)$.

if firms are symmetric in strategic investment (i.e.: SI and NSI games) the solution of the entry game is the same, independently of a firm's ability to invest strategically in R&D. Further, this provides once again evidence for our assertions in propositions 2 and 7, that can also be stated as:

Proposition 8 *In an international duopolist market, strategic R&D investment can only affect the competitive equilibrium between firms if firms differ at this level.*

Figure 3 shows the following market structure patterns. As in the previous games, for very high plant-specific fixed costs (G), both the home and the foreign firm choose to stay out of the market. For lower but still very high G , the exporting monopoly equilibrium by either the home or the foreign firm $((1, 0) (0, 1))$ emerges. Lowering G for intermediate levels makes the home exporting monopoly equilibrium $((1, 0))$ dominate. Maintaining G constant at intermediate levels but increasing t for very high levels involves the multinational monopoly by either the home or the foreign firm $((2, 0) (0, 2))$. In turn, for lower levels of G (but still high t), the home multinational monopoly equilibrium $((2, 0))$ emerges. For very low levels of G and intermediate to high t , the multinational duopoly $((2, 2))$ stands up. Decreasing t for very low levels (but keeping G at low levels), we have the exporting duopoly equilibrium $((1, 1))$. Finally, in the diagonal of the (G, t) space, for low t and low G the $(2, 1)$ equilibrium (home multinational *versus* foreign domestic) emerges; for intermediate to high t and G there is no-Nash equilibrium.

Then, in the (G, t) space we have a pattern of competition related with the plant-specific fixed costs. In fact, higher levels of G can benefit the firm that

cannot invest strategically. To see this, note that if we start with the $(1, 0)$ $(0, 1)$, or the $(2, 0)$ $(0, 2)$ or the $(1, 1)$ equilibriums, and G is reduced, we pass respectively to the $(1, 0)$, the $(2, 0)$ and the $(2, 1)$ equilibriums. As such, lower levels of G can support the more powerful firm to impose the higher efficiency it possesses.

Summing up, some important differences can be noted in relation to the *SI* and the *NSI* games. In the first place, three new types of market structures arise in equilibrium: home exporting monopoly $((1, 0))$, home multinational monopoly $((2, 0))$ and home multinational *versus* foreign domestic $((2, 1))$. Note that, contrary to what happens with most of the equilibriums in the *SI* and the *NSI* games, these new equilibriums are single Nash equilibriums. As such, asymmetries on strategic investment contribute to a reduction in the indeterminacy of the equilibrium of the first-stage. Second, the market structure foreign multinational *versus* home domestic $((1, 2))$ that emerges in the *SI* and the *NSI* games does not appear in the *HSI* game. Then, a domestic firm that does not invest strategically is unable to compete successfully with a multinational firm that invests strategically. All this shows that the home firm uses R&D strategically to affect the rival entry choices, namely to restrict entry or in case of entry by forcing the competitor to adopt the domestic strategy. The ultimate objective of the firm that can strategically invest is to achieve dominant positions in the market place.

Finally, the area of no-Nash equilibrium is reduced. This means that asymmetries at the level of strategic investment make it easier to find non-cooperative equilibriums, because the firm that invests strategically in R&D can impose its leadership upon the rival.

We believe then, that differences between firms on the capacity to invest strategically in R&D can explain in part the pattern of FDI between developed countries. Some of these countries are very similar in size and factor endowments, but this fact does not prevent them from having asymmetric FDI patterns (i.e.: some countries perform more FDI than others). Effectively, as we have said above, in a model that assumes symmetry at country level, but with no-R&D investment (like the HM model), only symmetric entry strategies arise in equilibrium (i.e.: symmetric FDI patterns). The introduction of R&D investment in the same type of model can allow a multinational firm to compete profitably with a domestic firm, i.e.: asymmetric strategies may emerge as a result of R&D investment. Nevertheless, it is not possible to know what country will lead in terms of multinational activity.

This can only be predicted by adding to the R&D model firms with different abilities to invest strategically. When this is done, asymmetric FDI patterns arise endogenously even in-between countries that are similar in every respect. Conversely, the country that hosts firms that invest strategically in R&D can lead the world market in terms of multinational activity. The reason for this is that firms with higher strategic investment capacity are able to influence rivals' strategic choices (outputs, R&D investment and entry) for their own benefit. This can for example explain the US multinationals dominance in the world economy (including Europe) as shown by Brainard (1997) and Markusen and

Maskus (2001). Several studies in fact demonstrate that US based multinationals are disproportionately higher investors in R&D, making these firms more competitive than foreign rivals (see Markusen, 1995 and Kravis and Lipsey, 1992). Our model presents some explanations for these empirical regularities. In the first place, the high investment in R&D and the supremacy of US multinational firms can be explained through the higher capacity of US firms to invest strategically in R&D in relation to foreign rivals. Second, R&D investment may be the basis for international specialization in multinational activity, explained by the different levels of R&D intensity across firms and countries³⁰.

Consequently, this debate can also be extended for FDI between developed and developing countries. It is widely known that developed countries dominate world FDI flows (see Markusen, 1995). A partial explanation for this can be the fact that firms from developing countries have lower capacity to invest strategically in R&D. As we have shown above a firm that does not invest strategically that competes against a firm that invests strategically has less probability to become multinational. Being that so, countries that host firms with less capacity to invest strategically will tend to have less FDI.

8 Robustness Analysis

In this section we perform robustness tests to the previous section results. The sensitivity analysis consists in checking the central case to different parameter values of D , θ and γ ³¹. The importance of this analysis is two-fold. First, it can tell us if the central case results hold for different values of the parameters. Second, it can give us important information on how firms' choice of foreign expansion is affected by market size (D) and by R&D investment characteristics (θ and γ).

8.1 Strategic Investment Game

The robustness analysis of the *SI* game shows some common trends. First, the central case is not sensitive to different market size values. The only difference that arises is that when market size increases the no-entry area shrinks, and the contrary if market size decreases. This is so because increasing market size increases profitability, promoting therefore entry (and the contrary for lower levels of D). In second place, results are sensitive to θ and γ , but increasing θ has the same effects of decreasing γ (and *vice-versa*). Furthermore, increasing

³⁰Blomstrom *et al.* (1990) show that different technological levels across countries can explain international trade in-between developed countries (in concrete US and Sweden), more than traditional factors such as differences in endowments. Our results, in turn, indicate that this can also be the case for FDI patterns. This can be a line for further research, namely empirically.

³¹The robustness test changes one parameter at a time, maintaining the remaining ones fixed at the central case values. For example, when checking the sensitivity of results to the market size parameter, we change D up and down from the central case value, while keeping $\gamma = 45$, $\theta = 5$ and $b = 2$.

θ (or decreasing γ) has the opposite effects of decreasing θ (or increasing γ). However, for very low levels of θ (or very high γ) some differences arise. Given this pattern, we only discuss results for increases in θ (or decreases in γ) and for very high reductions in θ (or very high increases in γ).

The first thing to be noted is that when θ is increased (or γ decreased) the central case picture does not change much, since the different market structures are replicated for similar areas in the (G, t) space. In consequence we do not show here the figure for high θ and low γ . Second, some small changes occur since the profit curves $\Pi_{2,2}$, $\Pi_{1,1}$ and $\Pi_{1,2}$ shift down; while the curves $\Pi_{2,1}$, $\Pi_{2,0}$, $\Pi_{1,0}$, $\Pi_{2,2} - \Pi_{1,2}$, $\Pi_{2,1} - \Pi_{1,1}$ and $\Pi_{2,0} - \Pi_{1,0}$ shift up. Also, as shown above analytically, the threshold level of trade costs that makes trade possible is reduced, i.e.: the *OMC* condition increases and as such trade is only possible for lower levels of trade costs.

The consequence of all this can be summarized as follows. The entry area increases relatively to the no-entering area, since $\Pi_{2,0}$ shifts up. This occurs because decreasing γ means a reduction in fixed costs and, therefore, lowers barriers to entry. Also high θ promotes entry, since firms can save more on production costs. More important however, the duopoly areas are reduced relatively to the monopoly areas, and the no-Nash equilibrium area shrinks³².

Decreasing θ for intermediate levels (or increasing γ for intermediate levels) has the opposite effects of increasing θ (or decreasing γ). However, some major changes occur for very low levels of θ or very high values of γ . In fact, reducing θ for very low levels (or increasing γ for very high values) changes the relative positions of some of the curves. This alters the relations between prevalent equilibrium market structures; the $\Pi_{2,0} - \Pi_{1,0}$ curve changes position with the $\Pi_{2,1} - \Pi_{1,1}$ and $\Pi_{2,2} - \Pi_{1,2}$ curves (see figure 4). Consequently, we have a new type of equilibrium, a multiple equilibria area: $(2, 0)$ $(0, 2)$ and $(1, 1)$. Note that this equilibrium is also present in the HM model. Also, as a result of these changes, the area of no-Nash equilibrium disappears and the area of multinational monopoly shrinks. Then, except for what concerns the $(2, 1)$ $(1, 2)$ equilibrium, for very low θ or very high γ , the *SI* game results approach those from the HM model. The behavior of the remaining market structures is similar to what happens when we increase γ or decrease θ for intermediate values (i.e.: the opposite of what we described above for high θ and low γ).

Summing up, if R&D is very efficient or not too costly, monopolies are promoted, duopolies discouraged and non-cooperative equilibriums harder to be achieved. This occurs because when such is the case, R&D competition is fiercer and sharing the market may not be the best option for firms. Consequently, a firm may choose (or be forced) to stay out of the market. The contrary occurs

³²The exporting duopoly area $((1, 1))$ decreases, because $\Pi_{2,1} - \Pi_{1,1}$ shifts up, while $\Pi_{1,1}$ shifts down. The multinational duopoly area $((2, 2))$ decreases given that the $\Pi_{2,2}$ curve shifts down and the threshold level of trade costs where the game is valid is reduced. On the contrary, the multinational monopoly area $((2, 0)$ $(0, 2))$ increases, since $\Pi_{2,2}$ shifts downwards while $\Pi_{2,0} - \Pi_{1,0}$ shifts up. The exporting monopoly area $((1, 0)$ $(0, 1))$ increases, once the $\Pi_{1,1}$ curve shifts down and the $\Pi_{2,0}$ curve shifts up. Also, the area of no-Nash equilibrium increases, because the $\Pi_{2,1} - \Pi_{1,1}$ curve is further away from the $\Pi_{2,0} - \Pi_{1,0}$ curve. Finally, the $(2, 1)$ $(1, 2)$ equilibrium is reduced, since $\Pi_{1,2}$ shifts down.

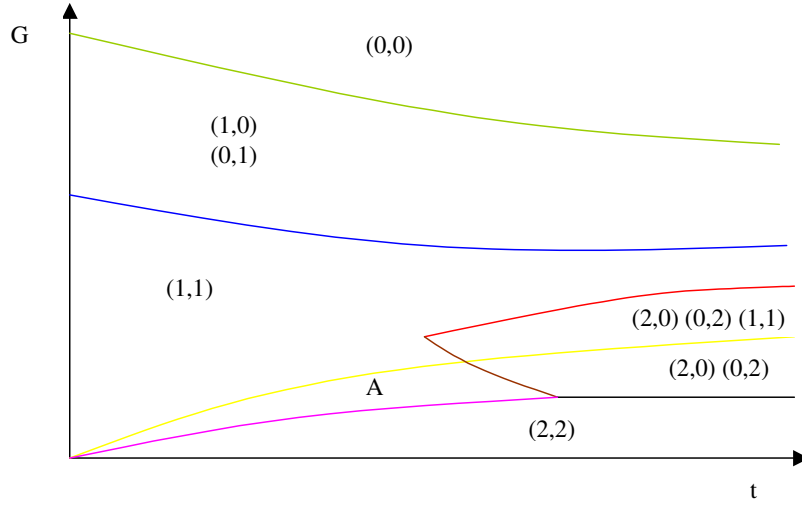


Figure 4: Solution of the entry stage, *SI* game: low θ or high γ . A: (2, 1) (1, 2).

for low θ or high γ . However, if θ is very low or γ very high, HM results are replicated with the exception of the asymmetric market structure cases ((2, 1) (1, 2)) that are proper of the R&D model only. This shows that when R&D competition is softer, non-cooperative equilibriums are easy to achieve and the R&D game approaches the no-R&D case.

8.2 Non-Strategic Investment Game

The *NSI* game shows a robustness analysis similar to the *SI* game. This proves once again our assertions in propositions 2, 7 and 8: the *SI* and the *NSI* games are very similar in what concerns competitive equilibriums given that in both cases firms have symmetric strategic investment capacity.

8.3 Home Strategic Investment Game

As in the *SI* and the *NSI* games, also in the *HSI* game results are not sensitive to market size (D). The only thing that happens for higher values of D is that the entering area increases (and the contrary for lower levels of D), however the relative equilibrium positions of the different market structures are not affected. Also, as in the previous games results are only sensitive to θ and γ and: decreasing γ has the same effects as increasing θ (and *vice-versa*); the effects of decreasing θ (or increasing γ) are the opposite of increasing θ (or decreasing γ); however, decreasing θ for very low values (or increasing γ for very high values) shows some different trends. Given this, as before for the *SI* game, we only discuss robustness results for increases in θ (or decreases in γ) and for very high

reductions in θ (or very high increases in γ).

We start first by looking at the effects of increasing θ (or decreasing γ). The first thing to be noted is that the general picture from the central case does not change much. For this reason we do not show the picture obtained from increasing θ or decreasing γ . Second, the profit curves $\Pi_{2,2}$, $\Pi_{1,1}$, $\Pi_{2,1}$, $\Pi_{2,0}$, $\Pi_{2,1} - \Pi_{1,1}$, $\Pi_{2,0} - \Pi_{1,0}$ and $\Pi_{1,2}^* - \Pi_{1,1}^*$ shift up; while $\Pi_{2,2}^*$, $\Pi_{1,1}^*$ and $\Pi_{1,2}^*$, $\Pi_{2,1}^*$ shift down. Third, and as shown analytically in a previous section, for high θ and low γ trade is restricted.

The first consequence of all this is that the no-entry area shrinks relatively to the entry area, since $\Pi_{2,0}$ shifts up. The second effect is that the home monopoly areas $((1,0)$ and $(2,0))$ increase, while all other equilibrium market structures are reduced³³.

Decreasing θ (or increasing γ) for intermediate values has the opposite effects as increasing θ or decreasing γ . However, for very low θ or very high γ , some new results emerge (see figure 5). First, there is a new area of multiple equilibria: $(2,0)$ $(0,2)$ and $(1,1)$. This happens because the $\Pi_{2,0} - \Pi_{1,0}$ curve changes position with the $\Pi_{2,1} - \Pi_{1,1}$ curve. As a result of this new area, the $(2,0)$ $(0,2)$ equilibrium is reduced and the area of no-Nash equilibrium disappears. All other results are similar to what happens when we increase γ or decrease θ for intermediate values, i.e.: the opposite of what we described above for high θ (or low γ).

In resume, the robustness checks of the *HSI* game shows some differences in relation to the *SI* game. In the *HSI* game for high θ or low γ , home monopoly equilibria $((2,0)$ and $(1,0))$ increase, while foreign monopoly equilibria are reduced and the same with the no-Nash equilibrium area. As we have seen above, in the *SI* game, on the contrary, both the home and the foreign monopolies increase as well as the no-Nash equilibrium area. Then, in the *HSI* game, the firm that can invest strategically is at an advantage when R&D is very efficient or not costly, since monopolies by this firm are promoted, while the contrary occurs for the firm that cannot invest strategically. This happens, because when R&D is very efficient or not costly the firm that can invest strategically can more easily impose the leadership of the market to the firm that has no such capacity, due to a tougher competitive environment. As a result, also the possibility of not achieving non-cooperative equilibria is reduced³⁴. On

³³The home exporting monopoly $((1,0))$ increases, because the $\Pi_{1,1}$ and the $\Pi_{2,1}$ curves shift up and the $\Pi_{1,1}^*$ and the $\Pi_{1,2}^*$ curves shift down. The home multinational monopoly $((2,0))$ expands, since $\Pi_{2,2}$ and $\Pi_{2,0} - \Pi_{1,0}$ shift up and $\Pi_{2,2}^*$ shift down. The exporting duopoly area $((1,1))$ is reduced, given that $\Pi_{1,1}^*$ shifts down and $\Pi_{2,1} - \Pi_{1,1}$ shifts up. The multinational duopoly $((2,2))$ decreases, because $\Pi_{2,2}^*$ shifts down and the threshold level of trade costs that makes trade possible is restricted. The $(2,0)$ $(0,2)$ equilibrium diminishes, both because, $\Pi_{2,2}$ shifts up and the threshold level of t is reduced relatively to the central case. The $(1,0)$ $(0,1)$ equilibrium shrinks, given that the $\Pi_{2,1}$ and the $\Pi_{2,2}$ curves shift up (more than $\Pi_{2,0}$). The $(2,1)$ equilibrium is reduced, since $\Pi_{2,1}^*$ shifts down. Finally, the no-Nash equilibrium area decreases because $\Pi_{2,1}^*$ and $\Pi_{1,1}^*$ shift down and $\Pi_{2,0} - \Pi_{1,0}$ shifts up.

³⁴Note that when θ is very low (or γ very high), the no-Nash equilibrium area disappears because of the new multiple equilibrium area. When θ is high (or γ low), the no-Nash equilib-

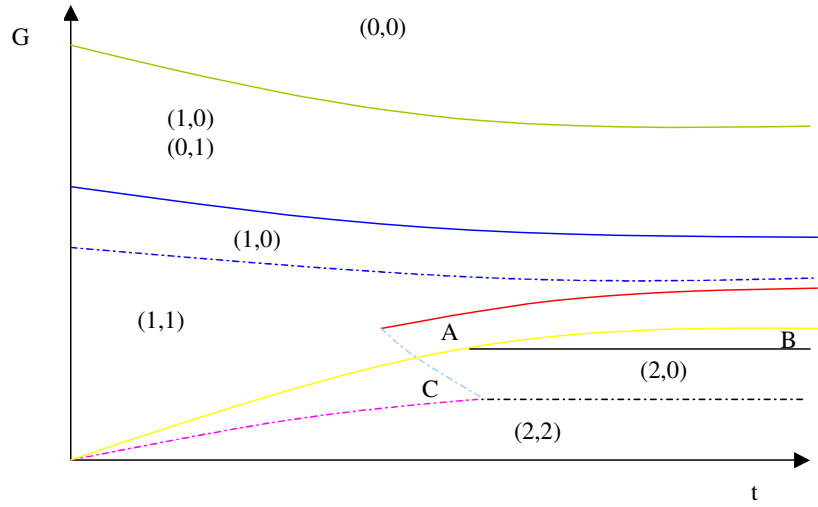


Figure 5: Solution of the entry stage, *HC* game: low θ or high γ . A: (2, 0) (0, 2) (1, 1); B: (2, 0) (0, 2); C: (2, 1).

the contrary, costly and not very efficient R&D protects the firm that invests non-strategically.

9 Discussion

In this paper we have looked at the relations between R&D, strategic investment and the mode of foreign expansion: export *versus* multinational. This analysis is particularly relevant for two reasons. First, R&D investment is at the heart of international competition, and is especially important in-between firms that are involved in multinational activity. Second, strategic investment is one of the distinguishing features of multinational firms, given that these types of firms are regarded as having higher power levels, at least when compared to purely domestic firms.

Keeping this in mind, we have developed a model that considers that firms compete both in outputs and R&D investment. A firm is more competitive when it invests more in R&D, since it leads to lower marginal costs. Furthermore, if a firm has capacity to invest strategically, it can use R&D investment not only to improve its own level of efficiency but also to affect the rival's strategic choices (entry, R&D and outputs). Three types of games that differ in the nature of strategic investment in R&D by firms were considered: *SI*, *NSI* and *HSI*. In the first, both firms can invest strategically in R&D; in the second, none

rium area is reduced due to the higher strategic investment capacity of the home firm that can more easily force non-cooperative equilibriums to the no-strategic investment foreign firm.

of the firms invests strategically; and in the third, only the home firm invests strategically. Conversely, what differentiates these three games are asymmetries between firms at the level of strategic investment.

The *SI* and the *NSI* games confirmed Horstmann and Markusen (1992) proximity-concentration trade-off between multinational activity and the exporting strategy. However, in both games a new market structure, not present in Horstmann and Markusen (1992), emerges in equilibrium: domestic *versus* multinational. This new equilibrium is a consequence of R&D investment: as long as multinational firms have access to R&D investment they can enter profitably in the market against domestic firms. Conversely, without R&D investment a multinational firm cannot out-compete a domestic firm. However, with R&D investment the multinational firm tends to invest more in R&D than the domestic firm. This higher capability of innovation of the multinational firm results from size effects that only this type of firm can explore. Furthermore, this advantage is so big that the multinational firm is more competitive than the exporting firm, not only in its own domestic market, but also in the rival market.

The *NSI* game presents similar results to the *SI* game. However, also some differences arise. Relatively to the *SI* game, in the *NSI* entry is promoted, monopoly equilibriums reduced and duopoly equilibriums increased. This happens because under the *NSI* game firms do not invest strategically, and consequently, a firm is not able to fully use innovation to promote the competitor's exit.

On the contrary, results of the *HSI* game differ from the *SI* and the *NSI* games. This shows that strategic investment can only change the equilibrium market structure if firms are asymmetric at this level. In fact, as we have seen, if firms have symmetric capacities to invest strategically in R&D (as is the case in the *SI* and *NSI* games), the same results are obtained independently of strategic investment: R&D *per se* is sufficient to explain the outcomes of such games. The same does not happen when firms differ in their capacity to invest strategically in R&D (as in the *HSI* game), given that endogenous asymmetries between firms at the level of productive efficiency arise. In fact, under all market structure configurations of the *HSI* game, the firm that invests strategically tends to invest more in R&D than the firm that does not do so. This is an important property of this game because most models in the field deal only with symmetric firms.

As a consequence, the *HSI* game presents some new results to the R&D-multinational model. First, three new types of market structures emerge in equilibrium: home exporting monopoly, home multinational monopoly and home multinational *versus* foreign domestic. Second, and contrary to the *SI* and the *NSI* games, the foreign (no-strategic investment) multinational *versus* the home (strategic investment) domestic market structure never arises in equilibrium. All this occurs because the more powerful firm (home) strategically over-invests in R&D in order to affect the rival's entry choices and be able to take the leadership in the market. Then, this result complements Fudenberg and Tirole (1984) finding that a firm over-invests in R&D to promote exit by

the rival: in our model a firm over-invests not only to influence the entry *versus* exit decision, but also to affect the mode of entry by the rival: one-plant versus two-plant.

We believe then that strategic investment can be a good explanation of asymmetric FDI patterns in-between countries similar in size and endowments (for example developed countries). In effect, traditional models predict that for countries similar in size and endowments, asymmetric FDI patterns cannot emerge. Such is not the case here. Even assuming symmetric countries in every respect (size and endowments), the introduction of different levels of strategic investment between firms leads to asymmetric FDI patterns, with some regions dominating in terms of multinational activity. The country that hosts the firm with higher strategic investment capacity can have a leader position in multinational activity and R&D investment, similar to US multinationals in world markets.

Furthermore, the strategic investment debate can also be extended to development issues. In fact, asymmetries in the capacity to strategically invest can give an additional explanation for the empirical regularity that developed countries account for the overwhelming proportion of FDI (both outward and inward FDI). If we consider that firms from developing countries have less capacity to strategically invest in R&D than firms from the developed countries, then the result will be that the former will have less multinational activity than the latter. The influence of strategic investment on FDI patterns (both across developed countries and in-between developed-developing countries) therefore deserves to be tested empirically.

Under all games, robustness analysis shows that the main results still hold when considering different parameters values. However, also some qualifications can be made related with the nature of R&D investment. Under both the *SI* and the *NSI* games, very efficient or not costly R&D promotes monopoly equilibriums and discourage duopolies relatively to the central case (and the contrary for costly or not efficient R&D). This is so, because tougher R&D competition may force a firm to stay out of the market. In turn in the *HSI* game, if R&D is very efficient or not costly, duopolies are also discouraged, but only monopolies by the firm with higher capacity to strategically invest are promoted, i.e.: monopolies by the firm with no power to strategically invest are discouraged. This shows that fiercer competitive environments benefit the firm with more capacity to strategically invest, since it can more efficiently use R&D to become leader of the industry. The reverse happens for costly or not efficient R&D. When that is the case the R&D games, especially the *SI* and *NSI* games, approach the results of the no-R&D case.

Finally, in terms of trade patterns, we have seen that trade is linked to the R&D intensity of the duopolist sector. If R&D is very efficient or not costly, trade is restricted; and the contrary if R&D is costly or not efficient. The rational for this is that when R&D significantly reduces marginal costs or is relatively inexpensive to invest, all firms are extremely competitive and can easily beat up foreign competition in their own domestic market, i.e.: international trade is discouraged. Also, access to international markets is inversely related with

strategic investment and differences between firms in their capacity to strategically invest. In fact, models where both firms can invest strategically (*SI* game) discourage trade relatively to models where none of the firms can invest strategically (*NSI* game). Models where firms are asymmetric in strategic investment (*HSI* game) reduce trade relatively to cases where firms are symmetric at this level (*SI* and *NSI* games). This is so, because strategic investment and differences in capacities to invest strategically make competition fiercer, which in turn makes it more difficult for firms to gain market shares on the rival's domestic market. Then firms by themselves can affect international trade patterns, and not only factor endowments (as in the Heckscher-Ohlin model) or preference for variety (as in Krugman, 1980). Given the novelty in terms of the trade implications of our model, these results should also be tested empirically.

10 Appendix

R&D First Order Condition The R&D maximization problem for the home firm is (ignoring sub-scripts for market structure):

$$\begin{aligned} \text{Max}_k \Pi &= (P - C)q + (P^* - C - t)x - \Gamma - \Delta \\ \text{s.r.} \quad &: C = c - \theta k \geq 0 \text{ and } k \geq 0 \end{aligned}$$

This problem can be solved using the Kuhn-Tucker method. First, write the Lagrangian function (denoting the Lagrange multiplier by λ):

$$L = \Pi + \lambda(c - \theta k)$$

The Kuhn-Tucker conditions are: $\partial L / \partial k \leq 0$, and $\partial L / \partial \lambda \geq 0$; non-negativity constraints on k and λ ; and complementary-slackness between each variable and the partial derivative of L with respect to that variable. The partial derivatives depend on the firm's capacity to strategically invest. In the case of strategic investment, we have:

$$\begin{aligned} \frac{\partial L}{\partial k} &= \frac{4}{3}\theta(q + x) - \gamma k - \lambda\theta \leq 0, & k \geq 0, & \text{ and } & k \frac{\partial L}{\partial k} = 0 \\ \frac{\partial L}{\partial \lambda} &= c - \theta k \geq 0, & \lambda \geq 0, & \text{ and } & \lambda \frac{\partial L}{\partial \lambda} = 0 \end{aligned}$$

The non-negativity condition ($\lambda \geq 0$) and the complementary-slackness condition ($\lambda(\partial L / \partial \lambda) = 0$) imply that if $\lambda = 0$, $k < c/\theta$; while for $\lambda > 0$, $k = c/\theta$ (since $\theta > 0$). For the complementary-slackness condition to be satisfied ($k(\partial L / \partial k) = 0$), we know that if $\lambda = 0$ (which implies $k < c/\theta$) and $k = \frac{4\theta}{3\gamma}(q + x)$, this condition and, consequently, also all Kuhn-Tucker conditions are always satisfied. On the contrary, if $\lambda > 0$ (which implies $k = c/\theta$), the complementary-slackness condition is never satisfied, since $k(\partial L / \partial k) \neq 0$ (i.e.: we do not have a corner solution). Then, the general R&D expression when the home firm invests strategically is:

$$k^{SI} = \frac{4\theta}{3\gamma} (q + x)$$

In turn, when firms invest non-strategically the general R&D expressions are:

$$k^{NSI} = \frac{\theta}{\gamma} (q + x)$$

To see this, just substitute the partial derivative of the Lagrangian in order to k for:

$$\frac{\partial L}{\partial k} = \theta (q + x) - \gamma k - \lambda \theta \leq 0$$

After, proceed in the same fashion as before. Also, the general R&D expressions for the foreign firm apply by symmetry.

Second Order Condition The SOC is found by substituting the general output expressions (equations 8 to 11) in the profit expressions (equations 7) and then computing the second order derivatives in order to k or k^* . In all the duopoly cases of the different strategic investment games we obtain:

$$\frac{d^2 \Pi_{i,j}}{dk_{i,j}^2} = -\frac{9\gamma b - 16\theta^2}{9b} < 0 \quad \text{for } i, j \neq 0$$

This implies that for the SOC to hold, we need that $\gamma > \frac{16\theta^2}{9b}$. In turn, in all the monopoly cases we have:

$$\frac{d^2 \Pi_{i,j}}{dk_{i,j}^2} = -\frac{\gamma b - \theta^2}{9b} < 0 \quad \text{for } i \text{ or } j = 0$$

In this case for the SOC to hold, we need that $\gamma > \frac{\theta^2}{b}$. Then, the most restricted SOC is $\gamma > \frac{16\theta^2}{9b}$.

Sign of φ (SI game) First note that φ is quadratic and convex in γ , with solutions $\gamma = \frac{8}{9} \frac{\theta^2}{b}$ and $\gamma = \frac{8}{3} \frac{\theta^2}{b}$. As such, $\varphi < 0$ for $\frac{8}{9} \frac{\theta^2}{b} < \gamma < \frac{8}{3} \frac{\theta^2}{b}$, and $\varphi > 0$ for $\gamma < \frac{8}{9} \frac{\theta^2}{b}$ and $\gamma > \frac{8}{3} \frac{\theta^2}{b}$. We need that $\gamma > \frac{8}{3} \frac{\theta^2}{b}$ for R&D investment to be positive under all cases of the SI game. This, therefore, implies that $\varphi > 0$. Further, since $\frac{8}{3} \frac{\theta^2}{b} > \frac{16\theta^2}{9b}$, then also the SOC is satisfied.

Proof of Proposition 1 (SI game) Proof $k_{1,2} < k_{1,2}^*$. $k_{1,2} - k_{1,2}^* = -8\theta \frac{D(3b\gamma - 8\theta^2) + 2t(3b\gamma - 2\theta^2)}{\varphi}$. This is negative since $\gamma > \frac{8\theta^2}{3b}$.

Proof $q_{1,2} < q_{1,2}^*$. $q_{1,2} - q_{1,2}^* = -\frac{t(4\theta^2 + 3b\gamma)}{3(3b\gamma - 8\theta^2)b}$. This is negative since $\gamma > \frac{8\theta^2}{3b}$.

Proof $x_{1,2} < x_{1,2}^*$. $x_{1,2} - x_{1,2}^* = -\frac{2t(3b\gamma - 2\theta^2)}{3(3b\gamma - 8\theta^2)b}$. This is negative since $\gamma > \frac{8\theta^2}{3b}$.

Proof $q_{1,2} < x_{1,2}^*$. $q_{1,2} - x_{1,2}^* = -4t\theta^2 \frac{9b\gamma - 8\theta^2}{b\varphi}$. This is negative since $\gamma > \frac{8\theta^2}{3b}$.

Sign of φ' (*NSI game*) First note that φ' is quadratic and convex in γ , with solutions $\gamma = \frac{2\theta^2}{3b}$ and $\gamma = \frac{2\theta^2}{b}$. As such, $\varphi' < 0$ for $\frac{2\theta^2}{3b} < \gamma < \frac{2\theta^2}{b}$, and $\varphi' > 0$ for $\gamma < \frac{2\theta^2}{3b}$ and $\gamma > \frac{2\theta^2}{b}$. We need that $\gamma > \frac{2\theta^2}{b}$ for R&D investment to be positive under all cases of the *NSI* game. This, therefore, implies that $\varphi' > 0$. Further, since $\frac{2\theta^2}{b} > \frac{16\theta^2}{9b}$, then also the SOC is satisfied.

Proof of Proposition 2 (*NSI game*) Proof $k_{1,2} < k_{1,2}^*$. $k_{1,2} - k_{1,2}^* = -\theta t \frac{3b\gamma - 2\theta^2}{\varphi'}$. This is negative since $\gamma > \frac{2\theta^2}{b}$.

Proof $q_{1,2} < q_{1,2}^*$. $q_{1,2} - q_{1,2}^* = -\frac{t(\theta^2 + b\gamma)}{3(b\gamma - 2\theta^2)b}$. This is negative since $\gamma > \frac{2\theta^2}{b}$.

Proof $x_{1,2} < x_{1,2}^*$. $x_{1,2} - x_{1,2}^* = -\frac{t(2b\gamma - \theta^2)}{3(b\gamma - 2\theta^2)b}$. This is negative since $\gamma > \frac{2\theta^2}{b}$.

Proof $q_{1,2} < x_{1,2}^*$. $q_{1,2} - x_{1,2}^* = -t\theta^2 \frac{3b\gamma - 2\theta^2}{b\varphi'}$. This is negative since $\gamma > \frac{2\theta^2}{b}$.

Sign of φ'' (*HSI game*) First note that φ'' is quadratic and convex in γ , with solutions $\gamma = \frac{4\theta^2}{18b} (7 + \sqrt{13})$ and $\gamma = \frac{4\theta^2}{18b} (7 - \sqrt{13})$. As such, $\varphi'' < 0$ for $\frac{4\theta^2}{18b} (7 - \sqrt{13}) < \gamma < \frac{4\theta^2}{18b} (7 + \sqrt{13})$, and $\varphi'' > 0$ for $\gamma < \frac{4\theta^2}{18b} (7 - \sqrt{13})$ and $\gamma > \frac{4\theta^2}{18b} (7 + \sqrt{13})$. We need that $\gamma > \frac{8}{3} \frac{\theta^2}{b}$ for R&D investment to be positive under all cases of the *HSI* game. Since $\frac{8}{3} \frac{\theta^2}{b} > \frac{4\theta^2}{18b} (7 + \sqrt{13}) > \frac{16}{9} \frac{\theta^2}{b}$, then also $\varphi'' > 0$ and the SOC is satisfied.

Proof of Proposition 4 (*HSI game*) Proof $k_{2,2} > k_{2,2}^*$. $k_{2,2} - k_{2,2}^* = 2D\theta b \frac{\gamma}{\varphi''}$. This is positive since $\gamma > \frac{8\theta^2}{3b}$.

Proof $k_{1,1} > k_{1,1}^*$. $k_{1,1} - k_{1,1}^* = \theta\gamma b \frac{(2D-t)}{\varphi''}$. This is positive since $\gamma > \frac{8\theta^2}{3b}$.

Proof $k_{2,1} > k_{2,1}^*$. $k_{2,1} - k_{2,1}^* = 2\theta \frac{Db\gamma + t(5b\gamma - 4\theta^2)}{\varphi''}$. This is positive since $\gamma > \frac{8\theta^2}{3b}$.

Proof $(q_{2,2} + x_{2,2}) > (q_{2,2}^* + x_{2,2}^*)$. $(q_{2,2} + x_{2,2}) - (q_{2,2}^* + x_{2,2}^*) = 4\theta^2 D \frac{\gamma}{\varphi''}$. This is positive since $\gamma > \frac{8\theta^2}{3b}$.

Proof $(q_{1,1} + x_{1,1}) > (q_{1,1}^* + x_{1,1}^*)$. $(q_{1,1} + x_{1,1}) - (q_{1,1}^* + x_{1,1}^*) = \frac{2\gamma\theta^2(2D-t)}{\varphi''}$. This is positive since $\gamma > \frac{8\theta^2}{3b}$.

Proof $(q_{2,1} + x_{2,1}) > (q_{2,1}^* + x_{2,1}^*)$. $(q_{2,1} + x_{2,1}) - (q_{2,1}^* + x_{2,1}^*) = \gamma \frac{4D\theta^2 + t(9b\gamma - 8\theta^2)}{\varphi''}$. This is positive since $\gamma > \frac{8\theta^2}{3b}$.

Relation between $k_{1,2}$ and $k_{1,2}^*$. $k_{1,2} - k_{1,2}^* = \theta \frac{2Db\gamma - t(11b\gamma - 8\theta^2)}{\varphi''}$. Then, $k_{1,2} > k_{1,2}^*$, if $D > t \frac{11b\gamma - 8\theta^2}{2b\gamma}$.

Proof $x_{2,1} > q_{2,1}^*$. $x_{2,1} - q_{2,1}^* = 2\theta^2 \frac{b\gamma D + t(5b\gamma - 4\theta^2)}{b\varphi''}$. This is positive since $\gamma > \frac{8\theta^2}{3b}$.

Relation between $q_{1,2}$ and $x_{1,2}^*$. $q_{1,2} - x_{1,2}^* = \theta \frac{2Db\gamma - t(11b\gamma - 8\theta^2)}{\varphi''}$. Then, $q_{1,2} > x_{1,2}^*$, if $D > t \frac{11b\gamma - 8\theta^2}{2b\gamma}$.

Proof $k_{2,1} > k_{1,2}^*$. $k_{2,1} - k_{1,2}^* = \theta b \gamma \frac{2D+t}{\varphi''}$. This is positive since $\gamma > \frac{8\theta^2}{3b}$.

Proof $(q_{2,1} + x_{2,1}) > (q_{1,2}^* + x_{1,2}^*)$. $(q_{2,1} + x_{2,1}) - (q_{1,2}^* + x_{1,2}^*) = \frac{4\gamma D \theta^2}{\varphi''}$. This is positive since $\gamma > \frac{8\theta^2}{3b}$.

Proof of Proposition 5 In the *SI* game, the derivatives of the *OMC* in relation to the R&D parameters are:

$$\begin{aligned}\frac{dOMC^{SI}}{d\gamma} &= -\frac{4}{9}t\theta^2 \frac{9b^2\gamma^2 + 32\theta^2(3b\gamma - 4\theta^2)}{b\gamma^2(3b\gamma - 8\theta^2)^2} < 0 \\ \frac{dOMC^{SI}}{d\theta} &= \frac{8}{9}t\theta \frac{9b^2\gamma^2 + 32\theta^2(3b\gamma - 4\theta^2)}{b\gamma(3b\gamma - 8\theta^2)^2} > 0\end{aligned}$$

The first derivative is negative and the second is positive since $\gamma > \frac{8\theta^2}{3b}$. In the *NSI* game, these derivatives are:

$$\begin{aligned}\frac{dOMC^{NSI}}{d\gamma} &= -t\theta^2 \frac{b^2\gamma^2 + 8\theta^2(b\gamma - \theta^2)}{3b\gamma^2(b\gamma - 2\theta^2)^2} < 0 \\ \frac{dOMC^{NSI}}{d\theta} &= \frac{2}{3}t\theta \frac{b^2\gamma^2 + 8\theta^2(b\gamma - \theta^2)}{b\gamma(b\gamma - 2\theta^2)^2} > 0\end{aligned}$$

The first derivative is negative and the second is positive since $\gamma > \frac{2\theta^2}{b}$. In turn in the *HSI* game:

$$\begin{aligned}\frac{dOMC^{HSI}}{d\gamma} &= -\frac{8}{3}t\theta^2 \frac{3b^2\gamma^2 + 4\theta^2(3b\gamma - 4\theta^2)}{b\gamma^2(3b\gamma - 8\theta^2)^2} < 0 \\ \frac{dOMC^{HSI}}{d\theta} &= \frac{16}{3}t\theta \frac{3b^2\gamma^2 + 4\theta^2(3b\gamma - 4\theta^2)}{b\gamma(3b\gamma - 8\theta^2)^2} > 0\end{aligned}$$

The first derivative is negative and the second is positive since $\gamma > \frac{8\theta^2}{3b}$.

Proof of Proposition 6 Proof $D_{OMC}^{HSI} > D_{OMC}^{SI}$. $D_{OMC}^{HSI} - D_{OMC}^{SI} = \frac{4t\theta^2(3b\gamma - 4\theta^2)}{9b\gamma(3b\gamma - 8\theta^2)}$. This is positive since $\gamma > \frac{8\theta^2}{3b}$.

Proof $D_{OMC}^{SI} > D_{OMC}^{NSI}$. $D_{OMC}^{SI} - D_{OMC}^{NSI} = t\theta^2 \frac{3b^2\gamma^2 + 4\theta^2(7b\gamma - 8\theta^2)}{9b\gamma(3b\gamma - 8\theta^2)(b\gamma - 2\theta^2)}$. This is positive since $\gamma > \frac{2\theta^2}{b}$.

11 References

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