FDI, R&D and Endogenous Productivity Asymmetries

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Abstract

We analyze the influence of endogenous productivity asymmetries between firms, in terms of competitiveness and size, on multinational activity. In the model, productivity depends on cost-reducing R&D investment. We then show that when firms differ on commitment power in R&D, the R&D leader, independently of being a multinational or a domestic firm, tends to invest more in R&D than the R&D follower. As a result of these productivity advantages, the R&D leader can more easily become multinational, because it has larger economies of scale in multinational activity. Therefore, in addition to the proximity-concentration trade-off, we identify another FDI determinant: technological competition.

Keywords: Market Structure, R&D Investment, Multinationals, Endogenous Asymmetric Firms.

JEL Classification: F23, C72, L11.

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1 Introduction

According to Markusen (1995, 2002) one of the most important stylized facts on foreign direct investment (FDI) is that multinational activity tends to be more important in industries and firms that have high levels of R&D to sales (see also Grubaugh, 1987; Morck and Yeung, 1992 and Lin and Yeh, 2005). The positive correlation between R&D investment and FDI is also confirmed by Kravis and Lipsey's (1992) empirical study on US multinationals. They show that high R&D investment by individual firms is associated with higher multinational shares and that the international competitiveness of US multinationals is determined by the level of investment in firm specific assets, such as R&D. Not surprising, then, that multinational firms in the US account for 80% of total R&D expenditure by private firms (Graham, 1996).

More recently, the literature on firm heterogeneity (Melitz, 2003) put forward another important stylized fact on FDI and multinational activity: multinational firms are usually bigger in size and more competitive than domestic firms (see Helpman et al., 2004 and Helpman, 2006)[1]. In this sense, Helpman et al. (2004) showed theoretically that by introducing exogenous productivity differences between firms, only the more productive firms become multinational, while the less productive ones either do not enter the market or are relegated to the domestic strategy[2].

It is therefore interesting to know why multinationals have this productivity advantage over domestic firms. In this paper we argue that this can be the result of R&D investment. The aim of this paper is then to analyze the influence of endogenous productivity asymmetries between firms, which result from R&D competition, on multinational activity. To do that we develop a horizontal FDI duopoly model (see Horstmann and Markusen, 1992 and Rowthorn, 1992)[3], where firms invest in process R&D investment that reduces marginal costs but increases firm-specific fixed costs (as in Leahy and Neary, 1997 and Petit and Sanna-Randaccio, 2000). Accordingly, the

[1] For example Helpman et al. (2004) find that in the US multinationals have approximately a 15% labor productivity advantage over exporters who did not engage in FDI, and a 39% labor productivity advantage over firms who engaged in neither export nor FDI.

[2] Nocke and Yeaple (2007) and Lu (2007), in turn, analyze the role of firm heterogeneity on FDI, the former on mergers and acquisitions and the latter on product life cycle dynamics.

[3] As in Helpman (1984) vertical FDI could be introduced by allowing for international differences in factor endowments. However, as Ihrig's (2005) empirical study on US FDI shows, technology issues are more important for horizontal FDI than for vertical FDI.

firms that invest more in R&D are more productive (i.e.: they are more competitive and larger in size), because they achieve lower marginal costs. In addition, firms differ in the capacity to commit to R&D decisions, i.e.: some firms are leaders in R&D (in the spirit of Stackelberg, 1934, and Bagwell, 1995).

In Horstmann and Markusen's (1992) horizontal FDI model, firms decide between exporting (domestic strategy) and establishing a plant in the foreign market (multinational strategy). 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 of the mode of foreign entry depends on a trade-off between concentration of production ("economies of scale" effect) and proximity to consumers ("firm size" effect, i.e.: multinationals are by assumption bigger, because by avoiding trade costs they can have higher sales in the destination market). This trade-off is then determined by the interplay between trade costs and the fixed cost of opening a foreign plant. Accordingly, the multinational option is favored when plant-specific fixed costs are low relatively to trade costs, the so-called proximity-concentration trade-off.

As noted by Petit and Sanna-Randaccio (2000), besides the "scale" and the "firm size" effects, the mode of foreign entry can also affected by a "technological" effect due for example to international competition in R&D investment. Having this in mind, Petit and Sanna-Randaccio (2000) endogenize both the firms' mode of foreign expansion and R&D investment[4]. R&D investment is modeled as a cost reducing activity following Leahy and Neary (1997). Petit and Sanna-Randaccio (2000), then, show that there is a positive relationship between multinational expansion and R&D investment. Accordingly, multinational firms invest more in R&D than domestic firms, because by having preferable access to foreign markets they have larger economies of scale in R&D. This allows multinationals to carry out more innovative activities than domestic firms.

Given our modeling strategy, similarly to other horizontal FDI models (such as Horstmann and Markusen, 1992, Petit and Sanna-Randaccio, 2000, and Helpman et al., 2004), multinational activity also arises here as a result of a proximity-concentration trade-off. But in our model this is only

[4]Some other papers analyze only the innovative activities of multinational firms, i.e.: multinationality is exogenous (see de Bondt *et al.*, 1988; Veugelers and Vanden Houte, 1990; and Wang and Blomstrom, 1992).

part of the story. We show that differences in R&D commitment power add a strategic technological dimension to the choice of foreign expansion. Accordingly, the R&D leader, independently of being an exporter or a multinational, tends to invest more in R&D and consequently to be more productive than the R&D follower[5]. As a result of higher productivity, the R&D leader can also more easily become a multinational, because it can explore larger economies of scale in multinational activity. Therefore, in addition to the proximity-concentration trade-off, we identify another FDI determinant: strategic international technological competition[6].

The rest of the paper is organized as follows. In the next section, we introduce the base model and define commitment power in R&D. After, we derive the production equilibrium. In the fourth section, we analyze how R&D and multinational activity affect firms' productivity level. In the fifth section, we compute profits under the different market structure configurations and perform some comparative static exercises. Then, in the sixth section we derive the entry equilibrium. We conclude by discussing results.

2 The Model

We consider an industry with two potential producer countries (home and foreign) and a third consumer country where all production is sold[7]. Each country can potentially host one firm, the home firm and the foreign firm. The home and the foreign firm, in case of entry, will produce the same homogeneous good but have to decide the location of the production plant. The production plant, can be located in either the firms' origin country (at home for the home firm and at foreign for the foreign firm) or in the third market. In the first case a firm becomes a domestic firm while in the second case a firm becomes a multinational firm. Accordingly, when a firm chooses the domestic strategy it serves the third market through exports, while when a

[5] In this sense, we differ from the approach of Helpman et al. (2004) where asymmetries between firms are exogenous. Our model however is, as we will see, much simpler than the one by Helpman et al. (2004).

[6] This theoretical prediction seems to be in accordance with Girma and Görg's (2006) empirical result that the productivity advantage of multinationals is more due to "technology" effects rather than to "firm size" effects.

[7] This modeling strategy is usually called the third market model (see Brander and Spencer, 1985). The third market assumption is made in order to abstract from domestic consumption.

firm opts for the multinational strategy it serves the third market through local production.

Since the model is symmetric, in most of the following we concentrate our attention in the home country (and the home firm). Equations for the foreign country (and for the foreign firm) apply by symmetry. Foreign variables are indicated by an asterisk.

The home and the foreign firm face the following indirect demand in the third country:

$$P_{i,j} = a - b\left(q_{i,j} + q^*_{i,j}\right) \tag{1}$$

where q is the sales of the home firm in the third market and q^* is the equivalent for the foreign firm. The sub-scripts (i, j) represent market structure. Accordingly, $i = 0, E, M$ is the international strategy of the home firm, where 0 stands for non-entry, E for the exporting strategy and M for the multinational strategy. Similarly $j = 0, E, M$ is the international strategy of the foreign firm[8]. Also, a and b are the intercept of demand and an inverse measure of market size, respectively.

Like in Leahy and Neary (1997), the home and the foreign firm invest in process R&D that reduces marginal costs (C) but increases fixed costs (Γ)[9]. For the home firm this amounts to:

$$\begin{aligned} C_{i,j} &= (c - \theta k_{i,j}) \\ \Gamma_{i,j} &= \gamma \tfrac{k^2_{i,j}}{2} \end{aligned} \tag{2}$$

where k is R&D investment by the home firm, θ is the cost-reducing effect of R&D, γ is the cost of R&D and c is the initial marginal cost. The foreign firm has a similar cost structure with $c = c^*$, $\theta = \theta^*$ and $\gamma = \gamma^*$. The symmetry in technology is assumed so that productivity asymmetries between the home and the foreign firm can only arise endogenously.

[8] Then, for example, $q_{M,E}$ is the home firm's sales in the third country when the home firm is a multinational and the foreign firm is an exporter (similarly $q^*_{M,E}$ is the foreign firm's exports to the third country when the home firm is a multinational and the foreign firm is an exporter).

[9] Contrary to Horstmann and Markusen (1992) we then endogenize the firm-specific fixed costs. This is particularly important, since firm-specific fixed costs intend to represent, as discussed in the introduction, strategic assets, such as R&D investment, which can hardly be seen as exogenous.

Throughout the paper it will prove useful, like in Leahy and Neary (1997), to define a parameter, η, that depends on market size (b) and on the R&D parameters (γ and θ):

$$\eta = \frac{\theta^2}{\gamma b} \tag{3}$$

A high η represents a larger return on innovative activities, since the cost-reducing effect of R&D (θ) weighted by $1/b$ (market size) is large relatively to its cost (γ). The reverse holds for low η. Then, η can be thought of as an indicator of the "relative return to R&D" (see Leahy and Neary, 1997 for this terminology). As we will see bellow the parameter η affects the fierceness (or softness) of competition.

We model multinational activity similar to what is standard in the literature (see Horstmann and Markusen, 1992). In particular, we assume that is more costly to operate a plant in the third market (multinational firm) than in the country of origin of the firm (domestic firm). Accordingly, we assume a plant specific fixed cost, Δ, that equals G when a firm is an exporter and that equals ρG, with $\rho > 1$, when a firm is a multinational, i.e.: $\Delta_E = G$ and $\Delta_M = \rho G$.

In this sense the home firm's profits can be written as:

$$\Pi_{i,j} = \left(P_{i,j} - C_{i,j} - t_i\right) q_{i,j} - \Gamma_{i,j} - \Delta_i \tag{4}$$

where $t = t^*$ represents trade costs, which are symmetric for both the home and the foreign firm. Like in Horstmann and Markusen (1992), only exporters face trade costs, i.e.: $t_E = t > 0$ and $t_M = 0$.

2.1 Commitment Power in R&D

The concept of commitment power, introduced first by Stackelberg (1934), refers to the strategic advantages of moving before rivals. Bagwell (1995), in turn, gives a precise definition of the assumptions behind games where firms have differences in commitment power. First, moves in the game are sequential with some players committing to actions before other players select their respective actions. Second, late-moving players perfectly observe actions selected by the first movers. In this paper we follow Bagwell's (1995) definition and apply it to investment in R&D.

In game terms, a firm has commitment power in R&D when it can commit to the output stage, i.e.: R&D levels are chosen in a previous stage to outputs. The contrary happens when a firm has no commitment power in R&D: the firm sets outputs and R&D levels simultaneously. Thus, when a firm has commitment power in R&D, it can use R&D to both improve own productivity levels and to affect the rival's strategic decisions. When a firm does not have commitment power in R&D, it can still use R&D to improve own productivity, but it cannot use R&D to affect the rival's strategic choices.

Like in a standard output-Stackelberg-leader set-up, commitment power in R&D, then, gives leader advantages to a firm that competes with another one that lacks such capability. However, differently from standard output-leader models, and as we will show below, firms with asymmetric commitment power in R&D can become endogenously asymmetric in marginal costs, i.e.: our model endogenizes productivity and, therefore, competitiveness and firm size. As we will see, this will have important implications in terms of the mode of foreign expansion by firms.

In this sense we assume that only the home firm has commitment power in R&D, i.e.: the home firms is the R&D leader and the foreign firms is the R&D follower[10]. The timing of the multinational game is then the following:

Stage 1 The home and the foreign firm decide the mode of entry in the third market: non-entry (0), export (E) or multinational (M).

Stage 2 The home firm chooses R&D (k).

Stage 3 The home firm chooses outputs (q) while the foreign firm chooses both outputs (q^*) and R&D levels (k^*).

Due to the first-mover advantage in R&D, then, the home firm can affect the output and R&D decisions of the foreign firm. However, and very importantly, given that the foreign firm decides on the entry mode before the R&D decision of the home firm, the R&D leader advantage of the home firm cannot influence the entry decision of the foreign firm (multinational

[10] Hamilton and Slutsky (1990), in turn, endogeneize the first mover advantage of Stackelberg leaders.

versus domestic *versus* no-entry)[11]. However, since R&D can affect firms' productivity level, R&D can also indirectly affect equilibrium market structure. Accordingly, more productive firms can more easily pay for the extra costs of multinational activity due to larger economies of scale. The aim of this set-up is then to analyze how asymmetries on commitment power in R&D affect directly firms' productivity and indirectly multinational activity.

3 Production Equilibrium

As usual the game is solved by backward induction. Output expressions are found by solving the first-order conditions (FOCs) for outputs. However, since these FOCs depend on market structure, different output expressions apply for different market structure cases. Accordingly, when both firms are multinationals we have:

$$\begin{aligned} q_{M,M} &= \frac{D+2\theta k_{M,M}-\theta k^*_{M,M}}{3b} \\ q^*_{M,M} &= \frac{D+2\theta k^*_{M,M}-\theta k_{M,M}}{3b} \end{aligned} \tag{5}$$

where $D = (a - c)$ is a measure of a firm "initial cost competitiveness" (i.e.: without R&D investment).

When both firms are exporters, we obtain:

$$\begin{aligned} q_{E,E} &= \frac{D-t+2\theta k_{E,E}-\theta k^*_{E,E}}{3b} \\ q^*_{E,E} &= \frac{D-t+2\theta k^*_{E,E}-\theta k_{E,E}}{3b} \end{aligned} \tag{6}$$

If the home firm is an exporter and the foreign firm is a multinational:

$$\begin{aligned} q_{E,M} &= \frac{D-2t+2\theta k_{E,M}-\theta k^*_{E,M}}{3b} \\ q^*_{E,M} &= \frac{D+t+2\theta k^*_{E,M}-\theta k_{E,M}}{3b} \end{aligned} \tag{7}$$

[11] In Petit and Sanna-Randaccio (2000) the timing of the game is the following: in the first stage the home and the foreign firm make the entry decision (non-entry, export or multinational), in the second stage the home and the foreign firm choose R&D levels, and in the third stage the home and the foreign firm compete in outputs. Therefore, also in Petit and Sanna-Randaccio (2000), R&D cannot affect entry strategies.

If the home firm is a multinational and the foreign firm is an exporter:

$$
\begin{aligned}
q_{M,E} &= \tfrac{D+t+2\theta k_{M,E}-\theta k^*_{M,E}}{3b} \\
q^*_{M,E} &= \tfrac{D-2t+2\theta k^*_{M,E}-\theta k_{M,E}}{3b}
\end{aligned} \tag{8}
$$

In turn, if the home firm has a multinational monopoly we get:

$$q_{M,0} = \tfrac{D+\theta k_{M,0}}{2b} \tag{9}$$

And if the home firm has an exporting monopoly it results:

$$q_{E,0} = \tfrac{D-t+\theta k_{E,0}}{2b} \tag{10}$$

Obviously, the expressions $q^*_{0,M}$ and $q^*_{0,E}$ are exactly the same as $q_{M,0}$ and $q_{E,0}$, with $k_{M,0}$ substituted for $k^*_{0,M}$ and $k_{E,0}$ substituted for $k^*_{0,E}$, respectively.

To derive the R&D expressions we now use the FOCs for R&D investment. These FOCs, however, depend not only on market structure but also on whether a firm has commitment power in R&D or not. To clarify this it might be helpful to write down the home firm's FOC for R&D:

$$\tfrac{d\Pi_{i,j}}{dk_{i,j}} = \tfrac{\partial \Pi_{i,j}}{\partial k_{i,j}} + \tfrac{\partial \Pi_{i,j}}{\partial q^*_{i,j}} \tfrac{dq^*_{i,j}}{dk_{i,j}} \tag{11}$$

The first and the second terms in right hand side of equation 11 are usually called the non strategic and the strategic motive for R&D (see Leahy and Neary, 1997 for this terminology)[12]. Two cases are possible related with these two terms. First, when a firm has commitment power in R&D and has a rival firm, the strategic term is non-zero, i.e.: R&D investment is strategic, because the firm can affect the rival's strategic choices (outputs and R&D). This is the case of the home firm in the duopoly cases. Second, when a firm has either no commitment power in R&D or it is a monopolist, the strategic term in equation 11 vanishes, i.e.: R&D investment is non strategic. This is the case of the foreign firm in all duopoly cases and of the home and the foreign firm in the monopoly cases, respectively. Summing up, the home firm in the duopoly cases has a FOC such as the one in equation 11. In turn, the foreign firm's FOC in all market structure cases is the following: $\frac{d\Pi^*_{i,j}}{dk^*_{i,j}} = \frac{\partial \Pi^*_{i,j}}{\partial k^*_{i,j}}$

[12] Note that the whole home firm´s FOC for R&D is: $\frac{d\Pi}{dk} = \frac{\partial \Pi}{\partial k} + \frac{\partial \Pi}{\partial q}\frac{dq}{dk} + \frac{\partial \Pi}{\partial q^*}\frac{dq^*}{dk}$. However, from the FOC for outputs we have that $\frac{\partial \Pi}{\partial q} = 0$.

for $j \neq 0$ and $i = 0, E, M$. The same happens for the home firm in the monopoly cases where the home firm's FOC equals: $\frac{d\Pi_{i,0}}{dk_{i,0}} = \frac{\partial \Pi_{i,0}}{\partial k_{i,0}}$.

We then have that the foreign firm's R&D expressions, independently of market structure, always equal:

$$k^*_{i,j} = \frac{\theta}{\gamma} q^*_{i,j}, \text{ for } j \neq 0 \text{ and } i = 0, E, M \tag{12}$$

In turn, R&D expressions for the home firm can take two forms. The first holds in the monopoly market structures where the home firm has a similar R&D expression to that of the foreign firm:

$$k_{i,0} = \frac{\theta}{\gamma} q_{i,0}, \text{ for } i = E, M \tag{13}$$

The second holds in the duopoly cases, where R&D investment by the home firm is now:

$$k_{i,j} = \frac{4\theta}{3\gamma} q_{i,j}, \text{ for } i, j \neq 0 \tag{14}$$

We can then see that in the duopoly cases, the home and the foreign firm have asymmetric incentives to invest in R&D (see equations 12 and 14). Accordingly, differences in commitment power in R&D create endogenous asymmetries between the home and the foreign firm, in terms of marginal costs and therefore productivity (i.e.: competitiveness and size). In particular, the home firm (the R&D leader) over-invests by a proportion of 4/3 relatively to the foreign firm (the R&D follower)[13]. As we will see in the next sections, this endogenous asymmetry property of our model is going to have important consequences in the equilibrium market structure.

We can now solve for the explicit output and R&D expressions for the different market structure cases to obtain:

$$\begin{aligned}
q_{M,M} &= \tfrac{3D(1-\eta)}{b(9-2\eta(7-2\eta))} \\
q^*_{M,M} &= \tfrac{D(3-4\eta)}{b(9-2\eta(7-2\eta))} \\
k_{M,M} &= \tfrac{4\theta D(1-\eta)}{b\gamma(9-2\eta(7-2\eta))} \\
k^*_{M,M} &= \tfrac{\theta D(3-4\eta)}{b\gamma(9-2\eta(7-2\eta))}
\end{aligned}$$

[13] This is so because in Cournot competition outputs are strategic substitutes (see Bulow et al. 1985), i.e.: if q^* increases, q decreases (and in consequence also the home firm's profits). But since when k increases, q^* decreases, then $\frac{\partial \Pi}{\partial q^*} \frac{dq^*}{dk} = \frac{\theta}{3} q > 0$, i.e.: the strategic effect of R&D is positive for the home firm.

$$
\begin{aligned}
q_{E,E} &= \tfrac{3(D-t)(1-\eta)}{b(9-2\eta(7-2\eta))} \\
q^*_{E,E} &= \tfrac{(D-t)(3-4\eta)}{b(9-2\eta(7-2\eta))} \\
k_{E,E} &= \tfrac{4\theta(D-t)(1-\eta)}{b\gamma(9-2\eta(7-2\eta))} \\
k^*_{E,E} &= \tfrac{\theta(D-t)(3-4\eta)}{b\gamma(9-2\eta(7-2\eta))}
\end{aligned}
$$

$$
\begin{aligned}
q_{E,M} &= \tfrac{3((D-t)(1-\eta)-t)}{b(9-2\eta(7-2\eta))} \\
q^*_{E,M} &= \tfrac{D(3-4\eta)+3t}{b(9-2\eta(7-2\eta))} \\
k_{E,M} &= \tfrac{4\theta((D-t)(1-\eta)-t)}{b\gamma(9-2\eta(7-2\eta))} \\
k^*_{E,M} &= \tfrac{\theta(D(3-4\eta)+3t)}{b\gamma(9-2\eta(7-2\eta))}
\end{aligned}
$$

$$
\begin{aligned}
q_{M,E} &= \tfrac{3(D(1-\eta)+t)}{b(9-2\eta(7-2\eta))} \\
q^*_{M,E} &= \tfrac{(D-t)(3-4\eta)-3t}{b(9-2\eta(7-2\eta))} \\
k_{M,E} &= \tfrac{4\theta(D(1-\eta)+t)}{b\gamma(9-2\eta(7-2\eta))} \\
k^*_{M,E} &= \tfrac{\theta((D-t)(3-4\eta)-3t)}{b\gamma(9-2\eta(7-2\eta))}
\end{aligned}
$$

$$
\begin{aligned}
q_{M,0} &= q_{0,M} = \tfrac{D}{b(2-\eta)} \\
k_{M,0} &= k_{0,M} = \tfrac{\theta D}{b\gamma(2-\eta)}
\end{aligned}
$$

$$
\begin{aligned}
q_{E,0} &= q_{0,E} = \tfrac{D-t}{b(2-\eta)} \\
k_{E,0} &= k_{0,E} = \tfrac{\theta(D-t)}{b\gamma(2-\eta)}
\end{aligned}
\tag{15}
$$

We restrict the parameter space so that trade costs do not forbid exports. If we assume otherwise, our model would be biased for the multinational strategy. It can easily be checked that in order to have trade in all market structure configurations we just need to guarantee that $q^*_{M,E} > 0$, or:

$$\begin{aligned} \hat{t} &< \tfrac{(3-4\eta)D}{2(3-2\eta)} \\ 0 &< \hat{\eta} < \tfrac{3}{4} \end{aligned} \tag{16}$$

The second equation above also assures that all second-order conditions (SOCs) are always satisfied (see appendix).

4 R&D and Firm's Competitiveness

Even with initially symmetric firms, our model can then predict endogenous asymmetries between firms on marginal costs (i.e.: firms with different levels of investment in R&D). As we have mentioned above, what drives this result is asymmetries in commitment power in R&D, which endogenize productivity asymmetries between the home and the foreign firm.

In this section we are going to show that the R&D leader (the home firm) tends to produce and invest more in R&D than the R&D follower (the foreign firm). As a result, the home firm also tends to be more competitive and bigger in size than the foreign firm. To see this, note first that the home firm has always a competitiveness and a size advantage over the foreign firm when the two firms have symmetric entry strategies (multinational and exporting duopolies) or the home firm is a multinational and the foreign firm is an exporter (see appendix):

$$\begin{aligned} k_{M,M} &> k^*_{M,M} \text{ and } q_{M,M} > q^*_{M,M} \\ k_{E,E} &> k^*_{E,E} \text{ and } q_{E,E} > q^*_{E,E} \\ k_{M,E} &> k^*_{M,E} \text{ and } q_{M,E} > q^*_{M,E} \end{aligned} \tag{17}$$

Furthermore, even when the home firm is in disadvantage in the entry strategy (i.e.: the home firm is domestic and the foreign firm is multinational, (E, M) market structure), the home firm can even so become more competitive than the foreign firm if trade costs (t) are not very high or the return on R&D (η) is not very low:

$$k_{E,M} > k^*_{E,M}, \text{ if } t < \tfrac{D}{11-4\eta} \text{ and } q_{E,M} > q^*_{E,M}, \text{ if } t < \tfrac{\eta D}{3(3-\eta)} \tag{18}$$

Accordingly, when trade costs are very high, the R&D leader advantage of the home firm cannot surpass the trade cost advantage of the foreign multinational firm.

More important for our paper, however, is the role of η. As we have just seen, high return on R&D (high η) makes the home firm more competitive relatively to the foreign firm, and the contrary low η. In other words, high η makes competition fiercer against the foreign firm, and the reverse for low η. The reason for this result is that for high η the R&D leader (the home firm) can more easily impose the R&D leader advantage on the R&D follower (the foreign firm). As we will see, this asymmetry in the behavior of the home firm and the foreign firm in relation to the parameter η will play an important role in the entry strategies of the two firms.

5 Profits and Entry Strategy

In this section we derive the profit expressions under the different market structure configurations and perform comparative static exercises in some of the parameters of the model. The profits expressions will be use in the next section to find the solution of the first stage of our game.

We start with the monopoly cases. Since a monopolist is not affected by commitment power in R&D, a monopoly by the home firm is exactly the same as a monopoly by the foreign firm:

$$\begin{aligned}\Pi_{M,0} &= \Pi^*_{0,M} = \tfrac{(2-\eta)D^2}{2b(2-\eta)^2} - \rho G \\ \Pi_{E,0} &= \Pi^*_{0,E} = \tfrac{(2-\eta)(D-t)^2}{2b(2-\eta)^2} - G \end{aligned} \tag{19}$$

In the duopoly cases, in turn, the home and the foreign firm will have different profit levels, since differences in commitment power in R&D make the two rivals endogenously asymmetric:

$$\begin{aligned}\Pi_{M,M} &= \tfrac{(9-8\eta)D^2(1-\eta)^2}{b(9-2\eta(7-2\eta))^2} - \rho G \\ \Pi^*_{M,M} &= \tfrac{(2-\eta)D^2(3-4\eta)^2}{2b(9-2\eta(7-2\eta))^2} - \rho G\end{aligned}$$

$$\Pi_{E,E} = \frac{(9-8\eta)(D-t)^2(1-\eta)^2}{b(9-2\eta(7-2\eta))^2} - G$$
$$\Pi^*_{E,E} = \frac{(2-\eta)(D-t)^2(3-4\eta)^2}{2b(9-2\eta(7-2\eta))^2} - G$$

$$\Pi_{E,M} = \frac{(9-8\eta)((D-t)(1-\eta)-t)^2}{b(9-2\eta(7-2\eta))^2} - G$$
$$\Pi^*_{E,M} = \frac{(2-\eta)((3-4\eta)D+3t)^2}{2b(9-2\eta(7-2\eta))^2} - \rho G$$

$$\Pi_{M,E} = \frac{(9-8\eta)(D(1-\eta)+t)^2}{b(9-2\eta(7-2\eta))^2} - \rho G$$
$$\Pi^*_{M,E} = \frac{(2-\eta)((3-4\eta)(D-t)-3t)^2}{2b(9-2\eta(7-2\eta))^2} - G \qquad (20)$$

To derive the entry equilibrium in the next section, however, we will also need to compute the firms' preferences over different market structure configurations. In fact, as shown in figure 1, the Nash solution of the entry stage is a three-by-three matrix with three strategic choices (non-entry, export and multinational) and two players (the home and the foreign firm). Then, we also have to compare for the home firm $\Pi_{M,M}$ with $\Pi_{E,M}$; $\Pi_{M,E}$ with $\Pi_{E,E}$; and $\Pi_{M,0}$ with $\Pi_{E,0}$ (and for the foreign firm $\Pi^*_{M,M}$ with $\Pi^*_{M,E}$; $\Pi^*_{E,M}$ with $\Pi^*_{E,E}$; and $\Pi^*_{0,M}$ with $\Pi^*_{0,E}$):

$$\Pi_{M,M} - \Pi_{E,M} = (9-8\eta)\, t \frac{2D(2-\eta(3-\eta))-t(4-\eta(4-\eta))}{b(9-2\eta(7-2\eta))^2} - G(\rho-1)$$
$$\Pi_{M,E} - \Pi_{E,E} = (9-8\eta)\, t \frac{2D(2-\eta(3-\eta))+t\eta(2-\eta)}{b(9-2\eta(7-2\eta))^2} - G(\rho-1)$$
$$\Pi_{M,0} - \Pi_{E,0} = \Pi^*_{0,M} - \Pi^*_{0,E} = t\frac{2D-t}{2(2-\eta)b} - G(\rho-1)$$
$$\Pi^*_{M,M} - \Pi^*_{M,E} = 2(2-\eta)\, t \frac{(D-t)(9-4\eta(3-\eta))-2D\eta(3-2\eta)}{b(9-2\eta(7-2\eta))^2} - G(\rho-1)$$
$$\Pi^*_{E,M} - \Pi^*_{E,E} = 2(2-\eta)\, t \frac{D(9-2\eta(9-4\eta))+2t\eta(3-2\eta)}{b(9-2\eta(7-2\eta))^2} - G(\rho-1) \qquad (21)$$

We are now in conditions to analyze the role of some of the parameters in the model on the firms' entry decision. We look in particular to the following parameters: plant-specific fixed costs (G), transport costs (t) and the return on R&D (η).

Home \ Foreign	M	E	0
M	$\Pi_{M,M}$, $\Pi^*_{M,M}$	$\Pi_{M,E}$, $\Pi^*_{M,E}$	$\Pi_{M,0}$, 0
E	$\Pi_{E,M}$, $\Pi^*_{E,M}$	$\Pi_{E,E}$, $\Pi^*_{E,E}$	$\Pi_{E,0}$, 0
0	0, $\Pi^*_{0,M}$	0, $\Pi^*_{0,E}$	0,0

Figure 1: Entry-Profit Matrix

In what refers to G, as it can be easily seen from equations 19 to 21, for both the home and the foreign firm, the multinational strategy is penalized for high G, and the reverse for the export strategy. In view of that, higher plant specific fixed costs makes it less attractive to opt by the multinational strategy in relation to the export strategy.

In terms of t, and as shown in appendix, for both the home and the foreign firm, the export strategy is penalized for high t, and the contrary for the multinational strategy:

$$\begin{aligned} \frac{d\Pi_{E,j}}{dt} &< 0 \text{ and } \frac{d\Pi^*_{i,E}}{dt} < 0 \text{ with } i,j = 0,E,M \\ \frac{d\Pi_{M,j}}{dt} &> 0 \text{ and } \frac{d\Pi^*_{i,M}}{dt} > 0 \text{ with } i,j = 0,E,M \\ \frac{d\Pi_{M,j-E,j}}{dt} &> 0 \text{ and } \frac{d\Pi^*_{i,M-i,E}}{dt} > 0 \text{ with } i,j = 0,E,M \end{aligned} \quad (22)$$

Accordingly, higher trade costs makes it more profitable for firms to be closer to consumers to save in trade costs (i.e.: multinational strategy).

We turn now to the role of η. In the monopoly cases, for both the home and the foreign firm, an increase in η represents an increase in profits and a promotion of the multinational strategy relatively to the exporting one (see appendix). However, the same does not happen in the duopoly cases. Accordingly, while in the monopoly market structures an increase in the return of R&D is good for profitability and for the multinational strategy, in the duopoly market structures this depends on the type of firm we are looking at, i.e.: if the firm is a R&D leader or a R&D follower.

In fact, and for most of the duopoly cases, while for the foreign firm (the R&D follower) an increase in η results in a reduction of profits, for the home firm (the R&D leader) this represents an increase in profits. Only in the (E, M) market structure the opposite of the above might occur (i.e.: an increase in η benefits the foreign firm but penalizes the home firm) if η is sufficiently low, i.e.: if R&D competition against the R&D follower is not very fierce. To prove this, note that the following relations hold (see appendix):

$$\begin{aligned}
&\tfrac{d\Pi_{M,M}}{d\eta} > 0,\ \tfrac{d\Pi_{E,E}}{d\eta} > 0 \text{ and } \tfrac{d\Pi_{M,E}}{d\eta} > 0 \\
&\tfrac{d\Pi_{E,M}}{d\eta} > 0 \text{ for high } \eta,\ \tfrac{d\Pi_{E,M}}{d\eta} < 0 \text{ for low } \eta \\
&\tfrac{d\Pi^*_{M,M}}{d\eta} < 0,\ \tfrac{d\Pi^*_{E,E}}{d\eta} < 0 \text{ and } \tfrac{d\Pi^*_{M,E}}{d\eta} < 0 \\
&\tfrac{d\Pi^*_{E,M}}{d\eta} < 0 \text{ for high } \eta,\ \tfrac{d\Pi^*_{E,M}}{d\eta} > 0 \text{ for low } \eta
\end{aligned} \tag{23}$$

Besides, in the duopoly cases, increases in η (i.e.: fiercer R&D competition against the R&D follower) promote the home firm to choose the multinational strategy relatively to the exporting one. For the foreign firm, the opposite occurs, except when η is sufficiently low (see appendix):

$$\begin{aligned}
&\tfrac{d\Pi_{M,j-E,j}}{d\eta} > 0 \text{ with } i,j = E,M \\
&\tfrac{d\Pi^*_{i,M-i,E}}{d\eta} < 0 \text{ for high } \eta,\ \tfrac{d\Pi^*_{i,M-i,E}}{d\eta} > 0 \text{ for low } \eta, \text{ with } i,j = E,M
\end{aligned} \tag{24}$$

The reason for these results is that for high η, the R&D leader (the home firm) can more easily impose the R&D leader advantage to the R&D follower (the foreign firm). In other words, a high η magnifies the productivity differences between the R&D leader and the R&D follower (i.e.: high η makes R&D competition against the R&D follower tougher). As a result, profits by the home firm increase and it is also more profitable for the home firm to choose the multinational strategy.

Summing up, higher t and lower G promote the multinational strategy over the export one. In turn, for the R&D leader, higher η tends to promote international activity (export and multinational) and to favour the multinational strategy over the domestic one. The reverse happens for the R&D follower. We can then see that while G and t work symmetrically for the home and the foreign firm, the opposite happens with the parameter η. The reason for this asymmetry in behavior is again asymmetries in commitment power in R&D.

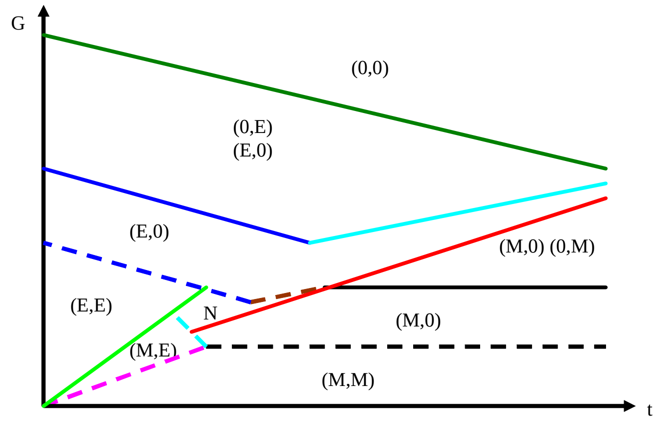

Figure 2: Entry Equilibrium: High η

6 Equilibrium Market Structure

As shown by Horstmann and Markusen (1992), to derive the equilibrium market structure of the game above, we just need to use the relations in the entry-profit matrix (figure 1) and equations 19 to 21. From here we can construct the entry equilibrium in the (G, t) space as shown in figures 2 and 3. Figure 2 arises for high values of η (i.e.: fierce R&D competition), while figure 3 arises for low η (i.e.: soft R&D competition)[14]. In particular, figure 2 is constructed with $D = 20$, $b = 1$, $\rho = 2$ and $\eta = 0.2$; and figure 3 is obtained with $D = 20$, $b = 1$, $\rho = 2$ and $\eta = 0.1$.

From figures 2 to 3, we can see that the solution of the entry stage of our model shares some similarities with other FDI models, such as Horstmann and Markusen (1992) and Petit and Sanna-Randaccio (2000). In fact, and due to the modeling strategy adopted, our model also displays the proximity concentration trade-off: for high trade costs and low plant-specific fixed costs the multinational strategy is preferred; while for high plant-specific fixed

[14]Figures 2 and 3 depict the following profit curves (colors indicated in parenthesis): $\Pi_{M,M}$ and $\Pi^*_{M,M}$ (black), $\Pi_{E,E}$ and $\Pi^*_{E,E}$ (blue), $\Pi_{E,M}$ and $\Pi^*_{E,M}$ (brown), $\Pi_{M,E}$ and $\Pi^*_{M,E}$ (cyan), $\Pi_{M,0}$ (orange), $\Pi_{E,0}$ (dark green), $\Pi_{M,M} - \Pi_{E,M}$ and $\Pi^*_{M,M} - \Pi^*_{M,E}$ (magenta), $\Pi_{M,E} - \Pi_{E,E}$ and $\Pi^*_{E,M} - \Pi^*_{E,E}$ (light green), $\Pi_{M,0} - \Pi_{E,0}$ (red). The home firm's profits curves are represented by solid lines while the foreign ones by dash lines.

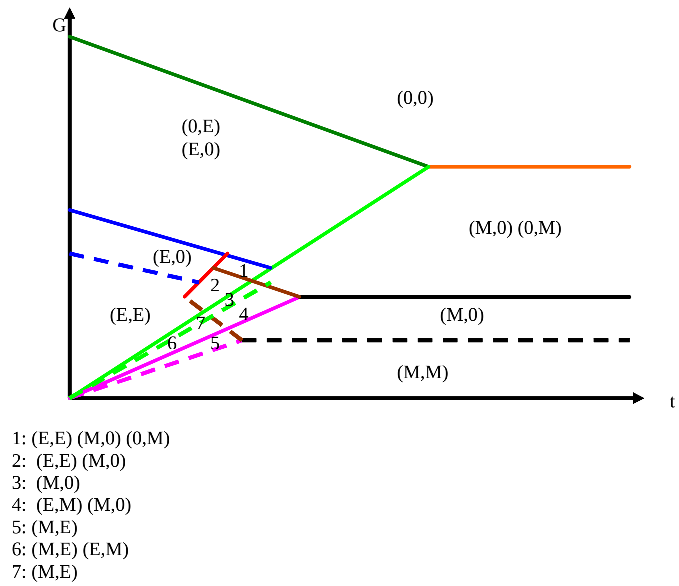

Figure 3: Entry Equilibrium: Low η

costs and low trade costs the exporting strategy is favored.

There are also some differences. For instances, our model predicts some market structure equilibriums not present in either Horstmann and Markusen (1992) or Petit and Sanna-Randaccio (2000). Accordingly, Horstmann and Markusen (1992) predict the following market structures in equilibrium: $(0,0)$, $(E,0)(0,E)$, (E,E), $(M,0)(0,M)$, (M,M) and $(E,E)(M,0)(0,M)$; while Petit and Sanna-Randaccio (2000) in addition also have the $(M,E)(E,M)$ market structure equilibrium and for some parameter values there is no-Nash equilibrium. In here, besides the market structure equilibriums previously mention, we can also have the following ones: $(E,0)$, $(M,0)$, (M,E), $(E,E)(M,0)$ and $(E,M)(M,0)$. Then, our model predicts a richer set of market structure equilibriums.

We have then to understand the emergence of these new equilibriums. Look first at the following market structure equilibriums: $(E,0)$, $(M,0)$ and (M,E). In here, and contrary to what occurs in Horstmann and Markusen (1992) and Petit and Sanna-Randaccio (2000), the previous mentioned equilibriums are obtained as single Nash equilibriums. Accordingly, in Horstmann and Markusen (1992) and Petit and Sanna-Randaccio (2000), the $(E,0)$,

$(M, 0)$ and (M, E) market structures only arise in mixed strategies equilibriums together with the $(0, E)$, $(0, M)$ and (E, M) market structures, respectively. We can then see that asymmetries on commitment power in R&D reduce the indeterminacy of the market structure equilibrium.

Other way to look at this is tho argue that in Horstmann and Markusen (1992) and in Petit and Sanna-Randaccio (2000) is not possible to predict which of the asymmetric market structures arise in equilibrium, i.e.: it can either be $(E, 0)$ or $(0, E)$, $(M, 0)$ or $(0, M)$, (M, E) or (E, M). However, as we know from the FDI data, international FDI patterns are very asymmetric. One way found in the FDI literature to predict which asymmetric FDI patterns will arise in equilibrium is to introduce some sort of asymmetry, such as for example asymmetries in market size (Pontes, 2001) or international differences in factor endowments (Markusen and Venables, 1998). In this paper, however, we are able to do this by introducing asymmetries in commitment power in R&D that lead to endogenous productivity asymmetries, which in turn support asymmetric entry strategies.

We can see these effects more clearly at work in the $(E, 0)$, $(M, 0)$ and (M, E) market structures equilibriums. In fact, and depending on market conditions (G and t), it is possible that only the more competitive firm (the R&D leader) can enter the market as an exporter or a multinational, while the less competitive firm (the R&D follower) just stays out of the market ($(E, 0)$ and $(M, 0)$ market structures equilibriums) or that the former becomes a multinational while the latter becomes an exporter ((M, E) market structure equilibrium). Then, similarly to Helpman et al. (2004), also in our paper productivity asymmetries between firms can separate multinationals from exporters and non-entrants. The difference relative to Helpman et al. (2004) is that in the present paper asymmetries between firms are endogenous, while in Helpman et al. (2004) they are exogenous.

To see this more clearly we make two vertical cuts in figure 2 for low and high trade costs, respectively figure 4 and 5. These two figures show that the decision between multinational, export and non-entry also depends on the R&D leader-follower relationship. Lower levels of G promotes symmetric duopoly equilibriums ((M, M) and (E, E)). In turn, low-medium G promotes a change from duopoly equilibriums to multinational or exporting monopolies equilibriums by the R&D leader (home firm) or to asymmetric duopolies equilibriums with the home firm being a multinational and the foreign firm being an exporter ($(M, 0)$, $(E, 0)$ and (M, E), respectively). Finally, medium-high G promotes multinational or exporting monopolies by either the home or

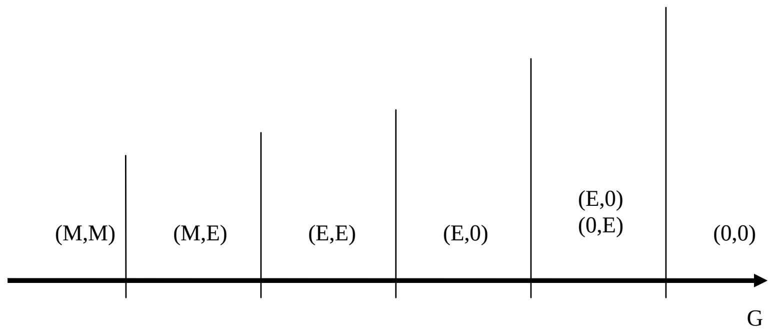

Figure 4: Multinational, Domestic, No-Entry: Low Trade Costs

the foreign firm ($(M,0)(0,M)$ and $(E,0)(0,E)$), while very high G promotes non-entry.

We are now just left to understand the following market structure equilibriums not present in Horstmann and Markusen (1992) and Petit and Sanna-Randaccio (2000): $(E,E)(M,0)$ and $(E,M)(M,0)$. Note that these equilibriums only arise for low η, i.e.: when R&D competition against the R&D follower is not very fierce. Not surprising, the foreign firm can only aspire to be a multinational against a domestic home firm for low η ($(E,M)(M,0)$ market structure). This means that a multinational firm that has no commitment power in R&D finds it difficult to compete successfully with a domestic firm that has commitment power in R&D, unless the return on R&D is very low. Accordingly, as we have already discussed before, for high return on R&D (i.e.: high η, figure 2), the R&D leader (the home firm) can more easily impose the R&D leader advantage. In turn, for low return on R&D (figure 3) the R&D follower (the foreign firm) can more easily face the R&D leader.

In our view, however, the important thing to notice is that while the proximity-concentration trade-off works symmetrically for both the home and the foreign firm, the "technological" effect (which runs through η) affects the two firms asymmetrically: high return on R&D (high η) favours the R&D leader (the home firm), while low return on R&D (low η) favours the R&D follower (the foreign firm). In this sense, this paper then introduces a new FDI determinant: international technological competition.

Summing up, relatively to other horizontal FDI models our model fea-

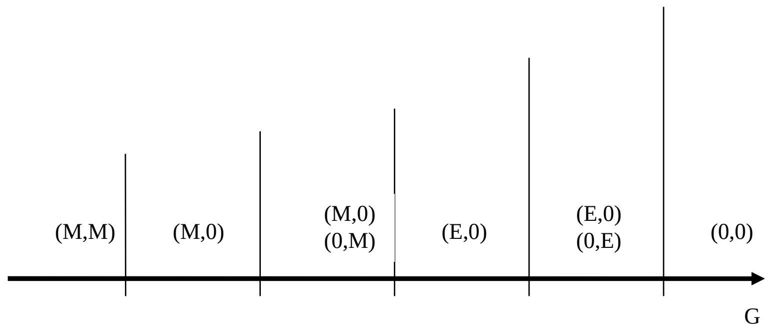

Figure 5: Multinational, Domestic, No-Entry: High Trade Costs

tures three main differences. First we endogenize productivity differences between firms. Second, we are able to predict single equilibriums for asymmetric market structure configurations ($(E, 0)$, $(M, 0)$ and (M, E)). Third, international R&D competition can affect asymmetrically different firms, depending on their commitment power in R&D. What drives these two results are asymmetries in commitment power in R&D. Accordingly, a R&D leader can become more productive (i.e.: larger in size and more competitive), because it can affect the R&D decisions of the rival. As a result, the R&D leader can also explore larger economies of scale in multinational activity. In this sense, when compared with a R&D follower, a R&D leader finds easy to pay for the extra costs of multinational activity (ρG instead of just G).

7 Conclusion

In this paper we have studied the interrelation between FDI, R&D and endogenous productivity asymmetries between firms. Productivity asymmetries arise as a result of differences in commitment power in R&D. In this way, we show that the R&D leader tends to invest more in R&D, and therefore, to have lower marginal costs. In other words, the R&D leader is more productive (i.e.: more competitive and larger in size) than the R&D follower. The productivity advantage of the R&D leader, in turn, can make it more easier to choose the multinational strategy. Accordingly by being bigger more productive, the R&D leader is able to explore larger economies of scale in multinational activity.

As a result, while high trade costs promote the multinational strategy and higher plant-specific fixed costs promote the exporting strategy, the return on R&D has asymmetric effects on the R&D leader and on the R&D follower. Higher return on R&D favors the R&D leader over the R&D follower. Low return on R&D in turn mitigates the R&D leader advantages of the R&D leader. In addition, higher return on R&D promotes the R&D leader to become a multinational while it promotes the R&D follower to become an exporter. What this means is that although the proximity-concentration trade-off affects all firms symmetrically, the "technological" effect can affect firms asymmetrically.

There are several issues that are disregarded in our paper. First we do not consider the question of the location of R&D (see for example Ekholm and Hakkala, 2007). Second, we do not take into account the welfare policies directed either to attract FDI or to promote R&D (see Sanna-Randaccio, 2002). Also, our framework should be extended to a more general context (as in Helpman et al., 2004). Future work should aim at incorporating these issues in the model introduced here.

A Appendix

Second-Order Conditions for R&D The SOC for the home firm in all the duopoly cases is:

$$\frac{d^2\Pi_{i,j}}{dk_{i,j}^2} = -\frac{\gamma(9-8\eta)}{9} < 0 \qquad \text{for } i,j \neq 0 \tag{25}$$

The SOC for the foreign firm in all the duopoly cases is in turn:

$$\frac{d^2\Pi_{i,j}^*}{d\left(k_{i,j}^*\right)^2} = -\frac{(3-2\eta)}{3} < 0 \qquad \text{for } i,j \neq 0 \tag{26}$$

Finally, in the monopoly cases the SOC is the same for both the home and the foreign firm:

$$\frac{d^2\Pi_{i,j}}{dk_{i,j}^2} = \frac{d^2\Pi_{i,j}^*}{d\left(k_{i,j}^*\right)^2} = -\frac{\gamma(2-\eta)}{2} < 0 \qquad \text{for } i \text{ or } j = 0 \tag{27}$$

Then, the most restricted SOC is $0 < \eta < \frac{9}{8}$.

Proof of Proposition 1

$$\begin{aligned}
k_{M,M} - k^*_{M,M} &= \tfrac{\theta D}{b\gamma(9-2\eta(7-2\eta))} > 0 \\
k_{E,E} - k^*_{E,E} &= \tfrac{\theta(D-t)}{b\gamma(9-2\eta(7-2\eta))} > 0 \\
k_{M,E} - k^*_{M,E} &= \theta\tfrac{D+t(10-4\eta)}{b\gamma(9-2\eta(7-2\eta))} > 0 \\
q_{M,M} - q^*_{M,M} &= \tfrac{\eta D}{b(9-2\eta(7-2\eta))} > 0 \\
q_{E,E} - q^*_{E,E} &= \tfrac{\eta(D-t)}{b(9-2\eta(7-2\eta))} > 0 \\
q_{M,E} - q^*_{M,E} &= \tfrac{D\eta+t(9-4\eta)}{b(9-2\eta(7-2\eta))} > 0
\end{aligned} \tag{28}$$

$$\begin{aligned}
k_{E,M} - k^*_{E,M} &= \tfrac{\theta(D-t(11-4\eta))}{b\gamma(9-2\eta(7-2\eta))} > 0 \text{ iff } t < \tfrac{D}{11-4\eta} \\
q_{E,M} - q^*_{E,M} &= \tfrac{D\eta-t(9-3\eta)}{b(9-2\eta(7-2\eta))} > 0 \text{ iff } t < \tfrac{\eta D}{3(3-\eta)}
\end{aligned} \tag{29}$$

Proof of Proposition 2

Profits *versus* trade costs For multinationals:

$$\begin{aligned}
\tfrac{d\Pi_{M,0}}{dt} &= \tfrac{d\Pi_{M,M}}{dt} = \tfrac{d\Pi^*_{M,M}}{dt} = 0 \\
\tfrac{d\Pi_{M,E}}{dt} &= \tfrac{2(9-8\eta)(D(1-\eta)+t)}{b(9-2\eta(7-2\eta))^2} > 0 \\
\tfrac{d\Pi^*_{E,M}}{dt} &= \tfrac{3(2-\eta)(D(3-4\eta)+3t)}{b(9-2\eta(7-2\eta))^2} > 0
\end{aligned} \tag{30}$$

For exporters:

$$\begin{aligned}
\tfrac{d\Pi_{E,0}}{dt} &= -\tfrac{D-t}{(2-\eta)b} < 0 \\
\tfrac{d\Pi_{E,E}}{dt} &= -\tfrac{2(9-8\eta)(D-t)(1-\eta)^2}{b(9-2\eta(7-2\eta))^2} < 0 \\
\tfrac{d\Pi_{E,M}}{dt} &= -\tfrac{2(9-8\eta)((D-t)(1-\eta)-t)(2-\eta)}{b(9-2\eta(7-2\eta))^2} < 0 \\
\tfrac{d\Pi^*_{E,E}}{dt} &= -\tfrac{(2-\eta)(D-t)(3-4\eta)^2}{b(9-2\eta(7-2\eta))^2} < 0 \\
\tfrac{d\Pi^*_{M,E}}{dt} &= -\tfrac{2(2-\eta)((D-t)(3-4\eta)-3t)(3-2\eta)}{b(9-2\eta(7-2\eta))^2} < 0
\end{aligned} \tag{31}$$

For multinational *versus* exporting strategy:

$$\begin{aligned}
\frac{d\left(\Pi_{M,M}-\Pi_{E,M}\right)}{dt} &= \frac{2(9-8\eta)(D(2-\eta(3-\eta))-t(4-\eta(4-\eta)))}{b(9-2\eta(7-2\eta))^2} > 0 \\
\frac{d\left(\Pi_{M,E}-\Pi_{E,E}\right)}{dt} &= \frac{2(9-8\eta)(D(2-\eta(3-\eta))+t\eta(2-\eta))}{b(9-2\eta(7-2\eta))^2} > 0 \\
\frac{d\left(\Pi_{M,0}-\Pi_{E,0}\right)}{dt} &= \frac{D-t}{(2+\eta)b} > 0 \\
\frac{d\left(\Pi^*_{M,M}-\Pi^*_{M,E}\right)}{dt} &= \frac{2(2-\eta)(D(9-2\eta(9-4\eta))-2t(9-4\eta(3-\eta)))}{b(9-2\eta(7-2\eta))^2} > 0 \\
\frac{d\left(\Pi^*_{E,M}-\Pi^*_{E,E}\right)}{dt} &= \frac{2(2-\eta)(D(9-2\eta(9-4\eta))+4t\eta(3-2\eta))}{b(9-14\eta+4\eta^2)^2} > 0 \qquad (32)
\end{aligned}$$

Profits *versus* Return on R&D For the monopoly cases:

$$\begin{aligned}
\frac{d\Pi_{M,0}}{d\eta} &= \frac{D^2}{4(2-\eta)^2 b} > 0 \\
\frac{d\Pi_{E,0}}{d\eta} &= \frac{(D-t)^2}{2(2-\eta)^2 b} > 0 \qquad (33)
\end{aligned}$$

For the home firm in the duopoly cases:

$$\begin{aligned}
\frac{d\Pi_{M,M}}{d\eta} &= \frac{D^2(1-\eta)(9-4\eta(5-\eta(7-4\eta)))}{b(9-2\eta(7-2\eta))^3} > 0 \\
\frac{d\Pi_{E,E}}{d\eta} &= \frac{2(D-t)^2(1-\eta)(9-4\eta(5-\eta(7-4\eta)))}{b(9-2\eta(7-2\eta))^3} > 0 \\
\frac{d\Pi_{M,E}}{d\eta} &= \frac{(D(1-\eta)+t)(D(9-\eta(20-4\eta(7-4\eta)))+t(90-16\eta(8-3\eta)))}{b(9-2\eta(7-2\eta))^3} > 0 \\
\frac{d\Pi_{E,M}}{d\eta} &= \frac{2((D-t)(1-\eta)-t)(D(9-4\eta(5-\eta(7-4\eta)))-t(99-4\eta(37-\eta(19-4\eta))))}{b(9-2\eta(7-2\eta))^3} \gtrless 0 \\
& < 0 \text{ for low } \eta \text{ and } > 0 \text{ for high } \eta \qquad (34)
\end{aligned}$$

For the foreign firm in the duopoly cases:

$$\begin{aligned}
\frac{d\Pi^*_{M,M}}{d\eta} &= -\frac{D^2(3-4\eta)(3+2\eta(15-2\eta(11-4\eta)))}{4b(9-2\eta(7-2\eta))^3} < 0 \\
\frac{d\Pi^*_{E,E}}{d\eta} &= -\frac{(D-t)^2(3-4\eta)(3+2\eta(15-2\eta(11-4\eta)))}{2b(9-2\eta(7-2\eta))^3} < 0 \\
\frac{d\Pi^*_{M,E}}{d\eta} &= -\frac{((D-t)(3-4\eta)-3t)(D(3+\eta(30-\eta(44-16\eta)))+t(138-\eta(168-\eta(80-16\eta))))}{2b(9-2\eta(7-2\eta))^3} < 0 \\
\frac{d\Pi^*_{E,M}}{d\eta} &= -\frac{(D(3-4\eta)+3t)(D(3+2\eta(15-2\eta(11-4\eta)))-t(141-2\eta(69-18\eta)))}{4b(9-2\eta(7-2\eta))^3} \gtrless 0 \\
& > 0 \text{ for low } \eta \text{ and } < 0 \text{ for high } \eta \qquad (35)
\end{aligned}$$

For the home firm, multinational *versus* exporting strategy:

$$\frac{d\left(\Pi_{M,M}-\Pi_{E,M}\right)}{d\eta} = 2t\frac{D(117-4\eta(74-\eta(75-2\eta(19-4\eta))))-t(198-\eta(395-4\eta(75-\eta(27-4\eta))))}{b(9-2\eta(7-2\eta))^3} > 0$$
$$\frac{d\left(\Pi_{M,E}-\Pi_{E,E}\right)}{d\eta} = 2t\frac{D(117-4\eta(74-\eta(75-2\eta(19-4\eta))))+t\left(81-\eta\left(99-4\eta^2(11-4\eta)\right)\right)}{b(9-2\eta(7-2\eta))^3} > 0$$
$$\frac{d\left(\Pi_{M,0}-\Pi_{E,0}\right)}{d\eta} = t\frac{2D-t}{2(2-\eta)^2 b} > 0 \qquad (36)$$

For the foreign firm, multinational *versus* exporting strategy:

$$\frac{d\left(\Pi^*_{M,M}-\Pi^*_{M,E}\right)}{d\eta} = 2t\frac{D(99-2\eta(153-2\eta(81-8\eta(5-\eta))))-t(207-2\eta(195-4\eta(36-\eta(13-2\eta))))}{b(9-2\eta(7-2\eta))^3} \lesseqgtr 0$$
$$\frac{d\left(\Pi^*_{E,M}-\Pi^*_{E,E}\right)}{d\eta} = 2t\frac{D(99-2\eta(153-2\eta(81-8\eta(5-\eta))))+4t(27-\eta(21+\eta(9-2\eta(7-2\eta))))}{b(9-2\eta(7-2\eta))^3} \lesseqgtr 0$$
$$> 0 \text{ for low } \eta \text{ and } < 0 \text{ for high } \eta \qquad (37)$$

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