Localized spillovers and foreign direct investment: a dynamic analysis

Maria-Luisa PETIT*,[a 0]

Francesca SANNA-RANDACCIO[a]

Roberta SESTINI[a]

[a] *Universita' di Roma "La Sapienza", 00185 Rome, Italy*

Abstract

It has been empirically shown that firms invest in foreign countries also with the aim to absorb technological knowledge. However, the recent literature on technological innovation and foreign expansion has not fully taken into account these features of foreign direct investment. Introducing this new element into the analysis implies assuming that multinationals and exporters operate with different degrees of technological spillovers. Our aim is to study how these differences in the transmission of knowledge may affect the firms' incentive to innovate and their behaviour in an international market, that is their choice between serving foreign markets via exports or foreign investments.

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[0] *Dipartimento di Informatica e Sistemistica, Universita' di Roma "La Sapienza", via Buonarroti 12, 00185 Rome, Italy. Tel. 39-06-48299231, fax. 39-06-48299218, e.mail: petit@dis.uniroma1.it. Research support from MIUR is gratefully acknowledged.

1 Introduction

The acceleration of firms international expansion via foreign direct investment (FDI) is one of the major causes of the rapid transformation of the world economy in recent years. Figures concerning the years 1985-1996 show that FDI grew twice as much as world trade during that period (UNCTAD-DTCI, 1997). Another interesting point is that FDI among developed countries still accounts for the bulk of world FDI flows: during the years 1990-95 developed countries accounted for 90.5% of world FDI outflows and 67% of world inflows (UNCTAD-DTCI, 1996). The traditional view that FDI flow to developing countries because of low costs of labour and/or capital is therefore being denied by empirical data.

Different reasons may push the firms towards multinational expansion like, for example, location near sources of technological innovation: firms tend to concentrate in regions (national or foreign) where the industry is characterized by strong technological externalities (see, e.g. Grunfeld, 1999). In fact, it is empirically shown (Neven and Siotis (1996), Fors (1998)) that firms may invest abroad with the aim to absorb technological knowledge. This is what is called "technology sourcing through FDI". On the other hand, Dunning (1997), studying 150 of the world's largest industrial enterprises, finds that FDI is likely to generate a greater feedback of technical knowledge than shallower forms of international involvement such as export or subcontracting. This means that local firms will also take advantage of the closer location of a multinational firm (MNE), absorbing more quickly the technological knowledge produced by the latter.

The recent literature on technological innovation and foreign expansion has not fully taken into account these features of FDI, apart from the above mentioned empirical studies. A few exceptions are the recent papers by Grunfeld (1999), Fosfuri and Motta (1999) and Siotis (1999) who discuss how localized spillovers may affect the firm's decision of how to serve a foreign market. These models, however - differently from the one presented here - are described in a static setting, and the amount of R&D undertaken by the firms is considered as exogenous.

Introducing this "location" element into the analysis implies assuming that MNEs and exporters operate with different degrees of technological spillovers. We shall assume in what follows that the degree of transmission of technological knowledge is higher between a local firm and a MNE producing the same good in that country (in both ways) than between a local firm and a foreign firm exporting the same good to that country. Vicinity increases the degree of knowledge transmission. Technological spillovers are therefore dependent on the mode chosen by the firms to serve the

foreign market, and, therefore, are no longer symmetric. This assumption is here incorporated into a dynamic oligopoly model in which both the firms' mode of foreign expansion and R&D levels are endogenously determined.

We describe a two-country model with two firms - one from each country - producing a homogeneous good. We assume process innovation, where the cost reducing technological innovations are an outcome of the firm's accumulated R&D. Each firm must take three different type of decisions: (i) the mode of foreign expansion (ii) how much to invest in R&D, (iii) how much to sell in each market (country). In particular, as regards point (i), each firm must decide among two possible strategies: export - EXP - (producing in the home country and exporting abroad), foreign direct investment - FDI - (producing in both countries thus becoming a MNE)[1].

Three different situations are thus described: a MNE duopoly, a exporting duopoly, a mixed duopoly (i.e. a MNE and a exporting-firm duopoly).

Equilibrium strategies concerning the mode of foreign expansion are obtained by applying a long-run investment selection approach, since the choice for the firms to become MNEs implies undertaking a foreign direct investment by establishing a new plant in the foreign country. That is we extend capital budgeting analysis to the framework of a duopolistic market. Equilibrium solutions for sales and investment in R&D are obtained by computing Markov equilibrium strategies. Firms decide first the mode of foreign expansion, then they decide how much to invest in R&D and how much to produce and sell in each market. The final structure of the market is therefore endogenously determined by the model.

The dynamic game model considered in this paper is non-linear. The analysis employs analytical tools whenever possible and numerical simulations otherwise. The numerical results are obtained by means of an algorithm based on a modified policy iteration method that is capable of computing Markov equilibria for some non-linear dynamic games outside the standard linear-quadratic formulation (see Appendix). In what follows, we shall often refer the reader to Petit, Sanna-Randaccio and Tolwinski (2000) (from now on P-SR-T, 2000) for more detailed descriptions of both the model and the analytical methods used. P-SR-T (2000) was based on the assumption that the intensity of technological spillovers was not affected by the location of production (i.e. we

[1] A third strategy: no expansion abroad, could easily be introduced, giving rise to two monopolistic situations when one of the firms chooses that strategy (see Petit et al. 2000). However, we have preferred to eliminate this possibility so as to avoid unnecessary complications. The essence of the results is independent of this assumption.

considered symmetric spillovers)[2].

The model has been framed in order to account for the most important features of firms' internationalization in the 1990s. That is we consider FDI flows between industrialized countries and therefore our model describes two identical countries and considers horizontal FDI. Asymmetries derive only from different degrees of technological spillovers, depending on the mode of foreign expansion. This allows us to focus on the main topic of the paper, that is on the impact that asymmetries in the degree of transmission of knowledge - due to differences in location - may have on the incentive to innovate and on the behaviour of firms operating in an international setting, that is on the choice of whether to serve a foreign market via export or FDI, and therefore on the resulting equilibrium market structure. In this framework, we also investigate whether the possibility to absorb higher knowledge is really an incentive for firms to invest abroad.

The paper is organized as follows. In section 2 we present the model. Section 3 describes the assumptions on technological spillovers between the firms. A numerical example is illustrated in section 4. Section 5 presents the main conclusions.

2 The Model

The dynamic model is described in discrete time. We consider two countries (country I and II) and two firms, firm 1 and 2, which manufacture the same homogeneous good in country I and II respectively.

On the demand side we consider a nonlinear stationary inverse demand function of the constant elasticity type, i.e.

$$p_I(q_{1,I}, q_{2,I}) = A_I(q_{1,I} + q_{2,I})^{-\beta_I} \qquad p_{II}(q_{1,II}, q_{2,II}) = A_{II}(q_{1,II} + q_{2,II})^{-\beta_{II}} \tag{1}$$

where p_I and p_{II} represent prices in country I and II respectively, and $q_{i,k}$ represents the sales of firm i in country k ($i = 1, 2, \quad k = I, II$). The parameters A_I, A_{II}, β_I and β_{II} are positive constants, $\beta_I = 1/B_I$, and $\beta_{II} = 1/B_{II}$, where B_I, B_{II} are demand elasticities in countries I and II respectively.

Learning resulting from investment in R&D characterizes the production process, implying that marginal and unit costs decrease as cumulative investment in R&D increases. That is, we consider

[2]See Sanna Randaccio (2002) for some welfare implications of localized versus non-localized spillovers.

process innovations that result in reductions in production costs.

Let $w_{it} \geq 0$ be the cumulative technological knowledge produced by firm i, resulting from (and represented by) R&D capital accumulation, i.e., the R&D capital accumulated by firm i from time 0 up to time t. Firm i's current rate of investment in R&D is denoted by u_{it}. The state variable w_{it} is, therefore, related to the decision variable u_{it} through the state equation

$$w_{it+1} = (1-\mu)w_{it} + u_{it} \quad (i = 1, 2) \tag{2}$$

where $\mu \in (0, 1)$ is the rate of depreciation of R&D capital (i.e. of the accumulated technological knowledge produced by firm i).

Since we also allow for the possibility of imperfect appropriability (technological spillovers between the firms), we introduce a spillover parameter $\alpha_i \in [0, 1]$. This means that the level of technological knowledge of firm i at each time t is given by its own accumulated technological knowledge up to t and by a fraction α_i of the knowledge accumulated by the other firm, i.e. $w_{it} + \alpha_i w_{jt}$ $(i, j = 1, 2; i \neq j)$. The spillover parameter α_i represents therefore an *incoming* spillover. In what follows we shall refer to the above expression $(w_{it} + \alpha_i w_{jt})$ as the firm's "knowledge" or "effective research".

Let $c_i(\underline{w})$ denote firm i's marginal (variable unit) cost per period, corresponding to the level of R&D capital $\underline{w}$ $(\underline{w} = (w_1, w_2))$. As indicated above, c_i will be assumed to decrease as technological knowledge grows. The magnitude of firm i's cost reduction at any time t is determined by[3]

$$c_i(\underline{w}) = c_i^0(1 + w_i + \alpha_i w_j)^{-\theta_i} \tag{3}$$

$i = 1, 2$, where c_i^0 is the initial variable unit cost of firm i.

The parameter θ_i, the rate of innovation, determines the rate at which the unit (variable) costs decline with accumulated knowledge from their initial level c_i^0. Under stationary equilibria, the accumulated R&D capital w_i will, in the long term, approach a steady state level, say $\hat{w_i}$, implying that the lowest unit variable cost that a firm can reach by investing in R&D will equal $c_i^0(1 + \hat{w_i} + \alpha_i \hat{w_j})^{-\theta_i}$.

Besides variable costs, each firm incurs an exogenous firm-specific fixed cost f in each period and a plant-specific fixed cost G. The parameter f captures the cost of some firm-specific activities such as advertising, marketing, distribution and managerial services, while G is the cost of building

[3]See Petit and Tolwinski (1999) for a similar specification.

a plant. The existence of fixed costs (both firm and plant specific) implies that the production process presents economies of scale: firm economies of scale and plant economies of scale.

In order to serve the foreign country, each firm can choose between export and FDI. Export implies additional marginal (and unit) transport cost s[4]. FDI, on the other hand, involves establishing a new plant in the other country, with additional plant specific fixed cost G. Therefore, a multinational will incur the cost of having two plants ($2G$), while an exporter will have the cost of only one plant[5].

Profits of the two firms will differ depending on the mode of foreign expansion considered. That is

1. *MNE duopoly.* Both firms undertake FDI to create a production subsidiary in the other country, i.e. become MNEs. Profits are then given by

$$\pi_i^{DD} = \sum_{t=0}^{\infty} \rho^t h_i^{DD}(w_{1t}, w_{2t}, q_{1,It}, q_{2,It}, q_{1,IIt}, q_{2,IIt}, u_{i,t}) - 2G \tag{4}$$

   where $\rho \in (0,1)$ denotes a discount factor, the superscript DD stands for MNE-duopoly and where

$$\begin{aligned} h_i^{DD}(\ldots) = A_I(q_{1,I} + q_{2,I})^{-\beta_I} q_{i,I} + A_{II}(q_{1,II} + q_{2,II})^{-\beta_{II}} q_{i,II} \\ -c_i^0(1 + w_i + \alpha_i^{DD} w_j)^{-\theta_i}(q_{i,I} + q_{i,II}) - u_i - (1/2)\ \gamma u_i^2 - f \end{aligned} \tag{5}$$

   $i = 1, 2, \;\; i \neq j, .$

   $h^D(\ldots)$ is a stationary function. The cost of investment in R&D is given by $u + (1/2)\ \gamma u^2$, $\gamma > 0$, where the quadratic term indicates the possibility of diminishing returns to the R&D investments (see, e.g., Cheng 1984).

2. *Exporting duopoly.* Both firms have only one plant and export to the other country. Profits are then given by:

[4]The parameter s may capture also some forms of policy induced discrimination. In fact a unit tariff, or some types of non-tariff barriers (as in Sanna-Randaccio (1996)), may be included in the model as an increase in the value of s.

[5]Since we consider two markets of similar dimensions, we assume that the cost of a plant will be the same in both countries. We also assume that G is a sunk cost.

$$\pi_1^{EE} = \sum_{t=0}^{\infty} \rho^t h_1^{EE}(w_{1t}, w_{2t}, q_{1,It}, q_{2,It}, q_{1,IIt}, q_{2,IIt}, u_{1,t}) - G \tag{6}$$

where

$$h_1^{EE}(\ldots) = A_I(q_{1,I} + q_{2,I})^{-\beta_I} q_{1,I} + A_{II}(q_{1,II} + q_{2,II})^{-\beta_{II}} q_{1,II}$$
$$-c_1^0(1 + w_1 + \alpha_1^{EE} w_2)^{-\theta_1} q_{1,I} - (c_1^0(1 + w_1 + \alpha_1^{EE} w_2)^{-\theta_1} + s) q_{1,II} - u_1 - (1/2)\ \gamma u_1^2 - f \tag{7}$$

and

$$\pi_2^{EE} = \sum_{t=0}^{\infty} \rho^t h_2^{EE}(w_{1t}, w_{2t}, q_{1,It}, q_{2,It}, q_{1,IIt}, q_{2,IIt}, u_{2,t}) - G \tag{8}$$

where

$$h_2^{EE}(\ldots) = A_I(q_{1,I} + q_{2,I})^{-\beta_I} q_{2,I} + A_{II}(q_{1,II} + q_{2,II})^{-\beta_{II}} q_{2,II}$$
$$-c_2^0(1 + w_2 + \alpha_2^{EE} w_1)^{-\theta_2} q_{2,II} - (c_2^0(1 + w_2 + \alpha_2^{EE} w_1)^{-\theta_2} + s) q_{2,I} - u_2 - (1/2)\ \gamma u_2^2 - f \tag{9}$$

where the superscript EE stands for exporting duopoly.

3. *Mixed duopoly: a MNE and a exporting firm.* One firm serves the other country by creating a new plant and the other firm by exporting. Assuming firm 1 to be the exporting firm and firm 2 the MNE (i.e. the ED-duopoly), discounted profits are given by:

$$\pi_1^{ED} = \sum_{t=0}^{\infty} \rho^t h_1^{ED}(w_{1t}, w_{2t}, q_{1,It}, q_{2,It}, q_{1,IIt}, q_{2,IIt}, u_{1,t}) - G \tag{10}$$

where

$$h_1^{ED}(\ldots) = A_I(q_{1,I} + q_{2,I})^{-\beta_I} q_{1,I} + A_{II}(q_{1,II} + q_{2,II})^{-\beta_{II}} q_{1,II}$$
$$-c_1^0(1 + w_1 + \alpha_1^{ED} w_2)^{-\theta_1} q_{1,I} - (c_1^0(1 + w_1 + \alpha_1^{ED} w_2)^{-\theta_1} + s) q_{1,II} - u_1 - (1/2)\ \gamma u_1^2 - f \tag{11}$$

and

$$\pi_2^{ED} = \sum_{t=0}^{\infty} \rho^t h_2^{ED}(w_{1t}, w_{2t}, q_{1,It}, q_{2,It}, q_{1,IIt}, q_{2,IIt}, u_{2,t}) - 2G \tag{12}$$

where

$$\begin{aligned} h_2^{ED}(\ldots) = A_I(q_{1,I} + q_{2,I})^{-\beta_I} q_{2,I} + A_{II}(q_{1,II} + q_{2,II})^{-\beta_{II}} q_{2,II} \\ -c_2^0(1 + w_2 + \alpha_2^{ED} w_1)^{-\theta_2}(q_{2,I} + q_{2,II}) - u_2 - (1/2)\ \gamma u_2^2 - f \end{aligned} \tag{13}$$

As mentioned above, the parameter α_i is defined in the range $0 \leq \alpha_i \leq 1$. The case of no spillovers ($\alpha_i = 0$) is obviously an extreme case of complete intellectual protection. More frequently, however, involuntary information leaks may occur as empirical research shows[6]. In this paper we assume that the transmission of technology incresases with proximity, that is a firm learns more from other firms when the geographical distance between them is reduced. Therefore, the transfer of technology between the two firms is stronger when firms build a plant in the foreign country, that is when they become multinationals. This creates an asymmetric situation related with the mode of foreign expansion, which explains why α_i can be different in each state: DD, EE or ED. The assumptions concerning the spillover parameter α_i are illustrated in the next section.

For analytical simplicity, the dynamic game is solved in three steps (see P-SR-T,2000 for further details): Equilibrium strategies for sales are computed first (for each market configuration considered), where the level of sales are expressed as functions of the R&D accumulated capital of both firms (i.e. the state variables). These strategies are then substituted into the firms' profit functions, so that the new objective function of a firm depends only on its rate of investment (u_i) and on the accumulated capital in R&D of both firms (w_1, w_2). Markov equilibrium strategies for R&D investments are then obtained and computed also for each market configuration, as both equilibrium strategies for sales and R&D investment depend on the firms' foreign expansion choices. Finally, the equilibrium market structure is obtained as the result of the decisions taken by the firms on the mode of foreign expansion. That is, we compute the Nash equilibrium (equilibria) of the matrix game described in Table 1, where the payoffs are the discounted profits of each duopolist (monopolist), as defined above.

The underlying assumption is that firms decide whether to make or not an investment abroad (i.e. to become MNEs or exporters) by applying capital budgeting analysis, that is by considering

[6]Empirical research shows in fact that rival firms normally learn about technical characteristics of new products and processes within twelve months of their introduction. See e.g. Mansfield (1985).

		firm 2	
		EXP	FDI
firm 1	EXP	π_1^{EE}, π_2^{EE}	π_1^{ED}, π_2^{ED}
	FDI	π_1^{DE}, π_2^{DE}	π_1^{DD}, π_2^{DD}

Table 1: A matrix game for the determination of equilibrium market structures.

the present value of the future net cash flows corresponding to the two alternatives, where net cash flows are here approximated by profits for simplicity (see, e.g. Mansfield 1993, Chaps. 1 and 14). Unlike traditional long-run investment planning theory which implicitly assumes that firms act as monopolists when taking their investment decisions, we assume that firms are aware of acting in a duopolistic market, and that, therefore, investment equilibrium strategies must be the result of a game between the two firms[7].

3 The transmission of technology

As it is well known, involuntary transmission of technological knowledge between rival firms can mainly be due to :

(a) reverse engineering

(b) industrial espionage

(c) personnel mobility between firms

(d) scientific publications and conferences

We here assume that the transmission of knowledge between the two firms depends on geographical distance, since some of the transmission mechanisms just mentioned (particularly (b) and (c)) are obviously weaker the higher the physical distance between the firms. Empirical evidence of this assumption can be found in, e.g., Jaffe et al. (1993), where it is shown - by using data on U. S. patent citations - that citations to domestic patents are more likely to be domestic, and more likely to come from the same state. We thus make the following assumptions on the spillover parameter:

[7]Since firms might be willing to reconsider their decisions on the mode of foreign expansion after given periods of time, this possibility can be examined by re-computing equilibrium strategies at different time intervals. We here omit this possibility in order to avoid further complications. The interested reader is referred to P-SR-T, 2000.

A1

The transfer of technology between two exporters is inferior than between two MNEs.

$\alpha_{ij}^{EE} < \alpha_{ij}^{DD}, \quad i = 1, 2, \quad j = I, II,$

where α_{ij} is the portion of the knowledge produced by other firm(s) which is absorbed by firm i in country j.

Recalling that in the ED case firm 1 is the exporter and firm 2 the MNE, the following assumption also holds:

A2

$\alpha_{1I}^{ED} < \alpha_{2I}^{ED}$.

In country I, the degree of transmission of technology from the local firm (firm 1) to the MNE (firm 2) (α_{2I}^{ED}) is stronger than the degree of transmission from the MNE to the local firm (α_{1I}^{ED}). This is due to the fact that firm 1 (the local firm) cannot fully exploit some of the technology transfer mechanisms indicated above (like personnel mobility or industrial espionage), since we have assumed that firm 2 is not carrying out research activities in country I. On the other hand, firm 2 can take advantage of all the knowledge transfer mechanisms, since it produces in country I where the local firm (firm 1) has its center of research activity[8].

A3

As the MNE in the ED case, multinational firms in the DD case can take advantage of all the information transfer mechanisms since both firms have a plant in the rival's home country. Therefore

$\alpha_{2I}^{ED} = \alpha_{2I}^{DD} = \alpha_{1II}^{DD}$.

A4

We assume that there is no cost of technology transfer from the parent firm to the subsidiary, and vice versa, thus there is complete transmission of information between the two. Therefore, the fraction of knowledge that firm i receives in country I is the same as the fraction it receives in country II. It thus follows that

$\alpha_{2I}^{ED} = \alpha_{2II}^{ED}$.

$\alpha_{1I}^{DD} = \alpha_{1II}^{DD}$

$\alpha_{2I}^{DD} = \alpha_{2II}^{DD}$.

[8]The assumption $\alpha_{1I}^{ED} = \alpha_{2I}^{ED}$ has also been considered, as will be seen in Sect. 4.

This assumption makes it possible to eliminate the country indexes (since exporting firms have only one plant located in the home country).

We can therefore simplify the relationships between the spillover parameters as follows:

$\alpha_i^{EE} < \alpha_i^{DD}, \quad i = 1, 2.$

$\alpha_1^{ED} < \alpha_2^{ED}$

$\alpha_2^{ED} = \alpha_1^{DD} = \alpha_2^{DD}$

As regards the relationship between α_1^{EE} and α_1^{ED}, the following assumptions can be made: (i) the intensity of spillovers received by the exporting firm 1 in the case of two exporters (α_1^{EE}) is the same as that received by the exporting firm 1 in the case firm 2 is a MNE (α_1^{ED}), that is $\alpha_1^{EE} = \alpha_1^{ED}$, or (ii) since in the ED case the subsidiary of firm 2 is producing in country I, some more information leaks from firm 2 towards firm 1 may occur with respect to the EE case, that is $\alpha_1^{EE} < \alpha_1^{ED}$. Therefore, it seems appropriate to assume:

$\alpha_1^{EE} \leq \alpha_1^{ED}$

If this is the case, and taking into account all the above inequalities, we can finally write:

$\alpha_i^{EE} \leq \alpha_1^{ED} < \alpha_2^{ED} = \alpha_i^{DD}$.

Therefore, even if the spillover parameter α is not an explicit function of location, as in Duranton (2000), it is related to location (in our case, to the mode of foreign expansion) by the above defined constraints that α must satisfy.

We also notice that, even if in the export-export case the distance between the two firms is the highest, this does not necessarily mean that there is no transmission of knowledge. The transmission can always take place through some of the usual channels of technological transfer, i.e. reverse engineering (from imported goods), and also from international personnel mobility, journals and conferences.

4 A numerical example

The model considered in this paper contains fifteen parameters, namely, f, G, s, ρ, γ, μ, α, θ_i, c_i^0, A_k, B_k, $(i = 1, 2; k = I, II)$, that have to be assigned numerical values. However, since we shall consider the symmetric case for all parameters except α_i, the number of parameters is reduced to eleven, given that $\theta_1 = \theta_2$, $c_1^0 = c_2^0$, $A_I = A_{II}$ and $B_I = B_{II}$.

Whenever possible these parameters have been chosen on the basis of available empirical results. This has been the case for the elasticity of demand B which has been set to 1.5 and for the rate of

innovation θ (for which empirical evidence provides an average value of around 0.30). Since θ can be considered as a cost elasticity, this means that a 1 percent increase in the level of technological knowledge of a firm will decrease unit production costs by 0.3 per cent. The discount rate r has been set to 0.06, with reference to an annual basis (note that $\rho = 1/(1+r)$), and the depreciation rate μ to 0.02. The value of γ, which affects the distribution of R&D investments over time, has been set to 2.

The parameter A is basically a scaling parameter for the demand curves and its value varies depending on the type of good produced. Since the qualitative character of the results is not significantly affected by these variations, we have set A to 20 in all experiments reported below.

The unit cost function parameters also depend on the particular good produced. The qualitative character of the results didn't seem affected by their magnitude. In our case, $c_1^0 = c_2^0 = 5$ has been used.

The values of f and G have been set to 2 and 40 respectively, while the unit transport cost s is equal to 0.5.

However, a very wide range of values of the parameters has been considered in the simulations in order to test the robustness of the results and the convergence properties of the algorithm (these simulations are available from the authors). In this section we present a selection of these results which highlight the effects of localized spillovers on R&D activities and on the equilibrium strategies for foreign expansion (i.e. on the equilibrium market structure). Our aim is to compare these results with those obtained in the assumption of symmetric spillovers (as shown in P-SR-T, 2000).

As mentioned in the previous section we assume that the degree of technological spillovers changes with location, therefore the values assigned to the spillover parameters are different depending on the mode of foreign expansion chosen by the firms. Considering the assumptions made in section 3, the following values of technological spillovers have been considered:

- when the firms are both exporters, the degree of transmission of information between them is very low, though not inexistent. That is, we consider $\alpha_i^{EE} = 0.2$.

- when the firms are both multinationals, the transfer of technology between the firms is much higher: we consider $\alpha_i^{DD} = 0.6$.

- when one of the firms is an exporter and the other a MNE, the exporting firm (firm 1) receives little information, though a bit more than in the case of two exporters, having now a plant of the MNE (firm 2) producing in its home country. That is, we assume that local firms learn more

when a foreign firm is producing in their country than when it is exporting to that country[9]. Therefore we set $\alpha_1^{ED} = 0.3$. The MNE, on the other hand, has a plant close to the main center of both production and research activity of the competitor (the exporter), and therefore absorbs information as in the case of two MNEs, that is $\alpha_2^{ED} = 0.6$.

Summing up, for the three different scenarios:

Export-Export: $\alpha_1^{EE} = \alpha_2^{EE} = 0.2$

FDI-FDI: $\alpha_1^{DD} = \alpha_2^{DD} = 0.6$

Export-FDI: $\alpha_1^{ED} = 0.3$; $\alpha_2^{ED} = 0.6$

We present here a selection of results focusing on[10]: (a) the effect of the different forms of international expansion on innovation and prices, and (b) the effect of localized spillovers on the equilibrium strategies for foreign expansion (i.e. on the equilibrium market structure)

4.1 The effect of the different forms of international expansion on innovation and prices

Let's first examine the effect of the mode of foreign expansion on the effective research of each firm (knowledge). Since the degree of transmission of knowledge between the firms is different for each different market structure, it is important to know, not so much the stock of research produced and accumulated by each firm (own R&D), but the total knowledge accruing to each of them (i.e. effective research) at each time t: $(w_i + \alpha_i w_j)$. In fact, it is this knowledge which determines the amount of (process) innovation introduced by each firm.

A comparison with the case in which localized spillovers are not considered (i.e. spillovers are symmetric) shows that the results may change substantially (see P-SR-T, 2000). In that case the knowledge accumulated by each firm over time was higher when the firms were MNEs rather than exporters, for all values of the spillover parameter α. As an example see Figure 2 where the evolution of each firm's knowledge for the three duopolies considered is reported, i.e. an MNE duopoly (indicated as MNE(DD) for each MNE firm), an exporting duopoly (indicated as EXP(EE) for each exporting firm) and a mixed duopoly (indicated as MNE(ED) for the firm that

[9] On this point see also Ethier and Markusen, 1996.

[10] Simulations have also been performed for other values of the spillover parameters, keeping obviously the type of asymmetries introduced in section 3. These modifications did not change the essence of the results

expands abroad via FDI and EXP(ED) for the firm that expands abroad via exports). The Figure corresponds to a value of the spillover parameter $\alpha = 0.5$, but the same conclusions holds for $\alpha = 0$ and $\alpha = 1$. This result was explained by the fact that the FDI choice - as compared to the export choice - eliminates transport costs and thus removes the cost advantage enjoyed by the locally based producer vis a vis the foreign firm, thus increasing competition in the product market. The higher competition leads to higher aggregate sales in each country in the DD case. The possibility to serve a larger market increases the profitability of the research expenditures (i.e. the return to a given reduction in unit cost is larger), and therefore becomes an incentive for the MNE firms to invest more in research than the exporting firms (see Fig. 1).

The higher investment in research of the MNE firms leads to a higher level of effective research (knowledge) in the case of two MNEs (the DD case) in comparison to the case of two exporters (the EE case). On the other hand, even if the MNE in the mixed case invests more in research than the MNE in the DD case (Fig. 1), the effective research is lower for the former (Fig. 2), since in the mixed duopoly case the MNE's own R&D is added to a share of the R&D accumulated by the exporter, which is much lower.

In any case - when spillovers are symmetric - the results show that, whatever market structure, MNEs are more innovative than exporters.

When the effects of geographical distance on the transmission of information between the firms is considered, the above results may no longer hold, as can be seen from Figure 3. In this case, the exporting firms (in the EE case) spend more in R&D over time than the MNEs (in the DD case). The reason for that being the stronger "free riding" effect when the two firms are MNEs (and $\alpha_i^{DD} = 0.6$) than when they are exporters (and $\alpha_i^{EE} = 0.2$). The "free riding" effect clearly prevails over the market dimension effect.

However, as regards the effects on innovation, we can observe from Fig. 4 that the level of knowledge is initially higher when the firms are both exporters than when they are both MNEs. However, after a number of periods (37 in our example), when the stock of R&D has grown enough, the level of knowledge accumulated by the firms in the case of two MNEs becomes higher. Therefore, even if in the DD case firms spend less in research, the level of innovation can be higher in the medium-long run due to the stronger degree of transmission of knowledge between the firms caused by geographical proximity.

In the mixed case, it is clear from Fig. 3 that the MNE invests more in R&D than the exporter, as in the case of symmetric spillovers (P-SR-T, 2000). Let us recall that, in the ED case,

the exporting firm (firm 1) is at disadvantage vis a vis its competitor when selling in country II due to transport costs, while the MNE firm (firm 2) is at par with the local firm in country I as it establishes local production. This asymmetry in the product stage generates an asymmetry in the R&D stage: the market for the exporting firm in country II is smaller than for the local producer, which reduces the profitability of the R&D investment of the former.

When geographically bounded spillovers are considered, this asymmetry in own R&D levels is reinforced by "free-riding" effects. In this case, the MNE firm is not really affected by "free-riding", since it knows that the competitor (i.e. the exporting firm) receives only a small part ($\alpha_1^{ED} = 0.3$) of the technological knowledge produced by the former. On the contrary, now the "free-riding" effect heavily influences the exporter. Recall that the MNE, having a plant in country I (the exporting country), receives a higher share of technological information from the exporter ($\alpha_2^{ED} = 0.6$). As a consequence firm 1 (the exporter) has less incentive to invest in R&D. It follows that the asymmetric market effect plus the asymmetric spillover effect causes the observed asymmetric behaviour as research is concerned.

However, as regards the level of knowledge of each firm in the ED case, it can be observed from Figs. 2 and 4 that the distance between the two levels of effective research is stronger when localized spillovers are considered. In fact, the MNE not only invests more in R&D, but is also able to take advantage of its position, close to the center of activity of the local firm (the exporter), and thus to absorb a great part of the research produced by the later. The result is a level of accumulated knowledge higher than that of firms that operate in different situations. On the contrary, the exporter, being far from the main center of research activity of the MNE, is able to absorb only a small part of the research produced by the competitor and therefore its level of accumulated knowledge is the lowest.

(figures 1, 2, 3 and 4 about here)

As for prices, the larger sales of a MNE duopoly (given the demand functions) should lead to prices that are lower in each country than in the case of a exporting duopoly. This was also the case for symmetric spillovers: the higher competition and the higher level of research in the DD case was obviously conducive to lower prices in both countries when the two firms expanded via FDI (P-SR-T, 2000). In our case, however, when localized spillovers are considered, exporting firms may have lower unit costs due to the higher level of knowledge with respect to MNEs in the

short run. Therefore, the final effect on prices depends on whether the higher competition effect prevails over the unit-cost effect. In the simulations carried out for the above mentioned values of α_i, prices where still lower in the DD case (Fig. 5), meaning that the higher competition effect did prevail, at least in the short run (in the long run, as shown in Fig. 4, knowledge is higher in the DD case, so that the two effects complement each other).

These results concerning prices when geographically bounded spillovers are considered are important. In fact, in the symmetric case, the FDI choice was always superior from the consumer welfare point of view, since a MNE duopoly produced both higher levels of innovation and higher competition in the product market. On the contrary, when localized spillovers are considered, the DD case gives rise to lower levels of R&D, and, what is more important, to lower levels of effective research for a rather long period (Figs. 3 and 4). The final effect of the FDI-FDI choice on consumer welfare cannot therefore be unambiguously determined.

(figure 5 about here)

In the mixed duopoly case the results are similar to the situation of symmetric spillovers: the level of prices is higher in the home country of the MNE (country II) than in the home country of the exporter (country I). Aggregate sales in the home country of the MNE (country II) are in fact lower than aggregate sales in the home country of the exporter (country I) since competition in country II (where only firm 2 produces) is lower than in country I, where both firms have a plant. In fact, the country II market is protected by the transport costs that only the exporter has to pay, which constitute a natural protective barrier. Therefore, even if the exporter (firm 1) in country I produces with higher unit costs due to its lower level of knowledge (see fig. 4), prices are lower in this country, meaning that the higher competition effect again prevails over the higher knowledge (lower unit-cost) effect.

4.2 The effect of localized spillovers on the equilibrium strategies for foreign expansion

We shall examine now how the firms will perform their choices on the mode of foreign expansion and how the assumptions on geographically localized spillovers may affect these choices.

		firm 2	
		EXP	FDI
firm 1	EXP	136.7, 136.7	69.1, 209.0
	FDI	209.0, 69.1	123.3*, 123.3*

Table 2: The effect of localized spillovers on the equilibrium market structure ($\theta = 0.3$, $\alpha_i^{EE} = 0.2$, $\alpha_i^{DD} = 0.6$, $\alpha_1^{ED} = 0.3$, $\alpha_2^{ED} = 0.6$)

note: * = Nash equilibrium

		firm 2	
		EXP	FDI
firm 1	EXP	119.7*, 119.7*	93.1, 110.2
	FDI	110.2, 93.1	88.2, 88.2

Table 3: The effect of symmetric spillovers on the equilibrium market structure ($\theta = 0.15$, $\alpha = 0.5$)

note: * = Nash equilibrium

As mentioned in section 2, in order to analyze this problem we need to know the discounted profits of each firm corresponding to the two different choices, i.e. EXP (exporting) and FDI (direct investment). Then we have to obtain the Nash equilibrium solution(s) of a game in strategic form between the two firms, where the pay-offs are the discounted profits of each single firm. This solution(s) will determine the equilibrium market structure of the model.

By computing the resulting discounted profits in the three duopoly cases (DD, EE and ED) we obtain the matrices reported in Tables 2, 3 and 4.

By comparing Table 2 with the results obtained when the effects of geographical location are not considered, we observe that the equilibrium solution is now FDI-FDI, whereas for the case of symmetric spillovers, FDI-FDI was an equilibrium only for some values of the spillover parameter (P-S-T, 2000).

Another, more interesting, comparison can be made by considering a lower productivity of research θ, since, in that case, the equilibrium market structure was always Export-Export (for all values of α) in the case of symmetric spillovers[11], as can be seen from Table 3, where the case

[11]The EXP-EXP equilibrium is more likely to take place when firms are less innovative and thus when θ is low, as shown in P-T-S, 2000.

		firm 2	
		EXP	FDI
firm 1	EXP	110.5, 110.5	81.1, 120.4
	FDI	120.4, 81.1	85.0*, 85.0*

Table 4: The effect of localized spillovers on the equilibrium market structure ($\theta = 0.15$, $\alpha_i^{EE} = 0.2$, $\alpha_i^{DD} = 0.6$, $\alpha_1^{ED} = 0.3$, $\alpha_2^{ED} = 0.6$)

note: * = Nash equilibrium

of $\alpha = 0.5$ is reported. However, when localized spillovers are considered, the equilibrium market structure is again FDI-FDI, as can be seen from Table 4.

Therefore, our results show that when the effects of geographically bounded spillovers are considered, an FDI-FDI equilibrium market structure is more likely to occur since there is an additional motivation for choosing this strategy: the possibility to absorb more technological knowledge from the rival firm. MNEs can thus make higher profits in relation to exporters (as compared with the case of symmetric spillovers) since they spend less in research than exporters in a exporting duopoly (as observed from Figure 1) and can reduce unit production costs by gaining access to a larger share of the research produced by the competitor. The conditions for an FDI-FDI equilibrium are in fact more easily verified when spillovers are localized.

We have assumed in this section that, in the mixed duopoly case, $\alpha_1^{ED} < \alpha_2^{ED}$ (i.e. assumption A2 in section 3). That is we have assumed that, in country I, the degree of transmission of R&D from the local firm to the MNE (α_2^{ED}) is higher than the degree of transmission from the MNE to the local firm (α_1^{ED}). This assumption gives a strong advantage to the MNE with respect to the exporter, since the MNE can easily free-ride on the competitor's R&D, but not vice versa. This is obviously a strong incentive for firms to become MNEs.

If we modify this assumption, by allowing also the local firm (i.e. the exporter) to free-ride on the MNE's R&D through the closer location of its subsidiary (e.g. Siotis, 1999), a firm would be under the effect of two contrasting tendencies: on the one hand, it would be encouraged to build a plant close to the competitor (i.e. in the foreign country) in order to take advantage of the latter's technological information. On the other hand, it would prefer to remain far away from the rival firm (trade only with the other country through exports) in order to avoid the competitors free-riding on its own R&D.

		firm 2	
		EXP	FDI
firm 1	EXP	136.7, 136.7	108.4, 179.4
	FDI	179.4, 108.4	123.3*, 123.3*

Table 5: The effect of localized spillovers on the equilibrium market structure ($\theta = 0.30$, $\alpha_i^{EE} = 0.2$, $\alpha_i^{DD} = 0.6$, $\alpha_1^{ED} = 0.6$, $\alpha_2^{ED} = 0.6$)

note: * = Nash equilibrium

We have analysed the effect of this new assumption on the firms' equilibrium strategies for foreign expansion by modifying the values of the spillover parameter in the Export-FDI case, i.e.:

$\alpha_1^{ED} = \alpha_2^{ED} = 0.6$

The equilibrium solution is still FDI-FDI, as in the previous scenarios. Therefore, the market will still be characterized by the presence of two MNEs, even if the incentive for the firms to invest abroad is certainly diminished, as can be seen from Table 5: the difference between profits when a firm is a MNE and the other is an exporter (the mixed case), is strongly reduced with respect to Table 2, when the exporter in the ED case could not free-ride on the MNE's R&D.

5 Conclusions

Taking into account the effects of geographical proximity between firms on the transmission of technology may change the results obtained when these effects are ignored.

Since proximity implies a higher level of transmission of technology, the FDI-FDI choice creates a free-riding effect which is stronger than in the Export-Export case. If this effect prevails over the market-dimension effect (as is the case in the examples considered), firms will invest more in R&D over time when both are exporters. This result is in contrast with the conclusions reached when spillovers were assumed to be symmetric: in that case investment in research was always higher when both firms were multinationals.

Even though firms accumulate a lower stock of own R&D in the FDI-FDI case, they can be more innovative in the medium-long run, since, due to geographical vicinity, each firm absorbs a higher share of the research produced by the competitor. Only in the short run, when the stock of

accumulated R&D is still low, the level of knowledge of each firm (i.e. effective research) can be higher in a exporting duopoly.

In the mixed duopoly case, the results are similar to those obtained when localized spillovers are not considered. Due to a market-size effect, the MNE firm invests more in R&D than the exporter. This result is further stressed when geographically localized spillovers are considered since, in this case, the "free-riding" effect influences mainly the exporter, which has therefore a lower incentive to invest in R&D. Also the distance between the levels of each firm's knowledge is stronger when localized spillovers are considered, since the MNE can take advantage of its position - close to the center of research activity of the local firm (the exporter)- and thus absorb a higher proportion of the research produced by the latter. On the contrary, the local firm cannot take advantage of the R&D produced by the rival firm (it absorbs only a lower proportion), since research is carried out only in the home country of the MNE.

As for prices, we need to consider two effects: the effect of competition, which is stronger in the FDI-FDI case (two firms producing in each country), and the effect of knowledge (effective research), which reduces unit production costs due to process innovation. Both effects worked in the same direction when localized spillovers where not considered: prices were always lower in the MNE duopoly case. When localized spillovers are taken into consideration, these two effects work in opposite directions in the short run, that is over the period in which the level of knowledge is higher for firms in the exporting duopoly scenario. The final effect on prices depends therefore on which of the two effects prevail. In our example, prices are always lower in the FDI-FDI case, meaning that the competition effect prevailed.

As regards equilibrium market structures, we have shown that, when localized spillovers are considered, an FDI-FDI equilibrium is more likely to occur. The possibility to absorb a higher proportion of the research produced by the competitor when investing in a foreign country is a further incentive for firms to invest abroad. In fact, MNEs can make higher profits in relation to exporters (when compared with the case of symmetric spillovers) since they spend less in research and have the possibility to reduce unit costs by using a stronger part of the research produced by the competitor.

In the light of these results it seems important to consider the specific nature of technological spillovers between firms and countries before approaching problems related to innovation and foreign expansion choices.

Some simplifying assumptions have been made in this paper, like those of centralized research

within the firm and technological symmetry between countries. Since these topics deserve attention, our future research will move in that direction.

APPENDIX

The Numerical Algorithm[12]

An approximation to Markov perfect Nash equilibrium for the dynamic games of Section 2 can be found by imposing a finite grid on the state space and then applying a modified policy iteration method (Tolwinski, 1989) to the resulting finite state Markov game. This approach is based on the fact that a strategy pair

$$\underline{\psi}^*(\underline{w}) = (\psi_1^*(\underline{w}), \psi_2^*(\underline{w})) \tag{14}$$

is a feedback Nash equilibrium for a dynamic game if there exist functions $V_i(\underline{w})$ for $i = 1, 2$ such that the following dynamic programming equations are satisfied.

$$V_1(\underline{w}) = \max_{u_1}\{l_1(\underline{w}, u_1) + \delta V_1(f(\underline{w}, u_1, \psi_2^*(\underline{w})))\} \tag{15}$$

and

$$V_2(\underline{w}) = \max_{u_2}\{l_2(\underline{w}, u_2) + \delta V_2(f(\underline{w}, \psi_1^*(\underline{w}), u_2))\} \tag{16}$$

where, in our case, $l_i(\underline{w}, u_i),\ i = 1, 2$, is given, for each different situation considered, by each of the profit functions described in sect. 2 in the text, after substitution of equilibrium strategies for sales has been performed (see P-S-T, 2000 for further details), and where

$$f(\underline{w}, u_1, u_2) = [(1-\mu)w_1 + u_1, (1-\mu)w_2 + u_2]^T \tag{17}$$

The dynamic programming equations defined above can be solved on a finite grid W_h imposed on the state space

$$W = \mathcal{R}^+ \times \mathcal{R}^+ \tag{18}$$

where

$$W_h = \{(w_i = ih, w_j = jh) : i = 0, \ldots, M; j = 0, \ldots, N\} \tag{19}$$

with $h > 0$ and

$$M = \text{entier}((w_{1max}/h)),\ N = \text{entier}((w_{2max}/h)) \tag{20}$$

[12]The numerical algorithm is due to Boleslaw Tolwinski

The equilibrium strategies $\psi_i(\underline{w})$ and value functions $V_i(\underline{w})$ $(i = 1, 2)$ are computed only for $\underline{w} = (w_1, w_2) \in W_h$. Notice that W_h is bounded from above by parameters w_{1max} and w_{2max}. This restriction is of little consequence as long as w_{1max} and w_{2max} are large enough to guarantee that $0 < \hat{w}_1 < w_{1max}$ and $0 < \hat{w}_2 < w_{2max}$, where $(\hat{w}_1, \hat{w}_2)$ is the steady state generated by equilibrium strategies. The computation of Markov strategies for the finite state dynamic game defined on W_h can be carried out by means of the following algorithm.

Algorithm (Modified Policy Iteration)

1. Select initial approximations $V_i^0(\underline{w})$ to $V_i(\underline{w})$ for all $\underline{w} \in W_h$, $i = 1, 2$. Set k to 0.

2. for every $\underline{w} \in W_h$, compute a Nash equilibrium point, say (u_1^*, u_2^*), of the static game defined by strategy spaces $\mathcal{R}^+$, $\mathcal{R}^+$, and payoff functions $R_i(\underline{w}; u_1, u_2)$, $i = 1, 2$, where

$$R_i(\underline{w}; u_1, u_2) = l_i(\underline{w}, u_i) + \delta V_i^k(f(\underline{w}, u_1, u_2))$$

   Set $\underline{\psi}^k(\underline{w}) = (\psi_1^k(\underline{w}), \psi_2^k(\underline{w})) = (u_1^*, u_2^*)$.

3. Compute approximate values of the payoff functionals corresponding to the strategy pair $\underline{\psi}^k(\underline{w})$ by applying a few, say $m \geq 1$, Jacobi iterations to the system

$$V_i(\underline{w}) = l_i(\underline{w}, \psi_i^k(\underline{w})) + \delta V_i(f(\underline{w}, \underline{\psi}^k(\underline{w})))$$

   for $\underline{w} \in W_h$ and $i = 1, 2$. More precisely, set $V_i^{k,0}(\underline{w}) = V_i^k(\underline{w})$ and for $j = 0, \ldots, m-1$ compute

$$V_i^{k,j+1}(\underline{w}) = l_i(\underline{w}, \psi_i^k(\underline{w})) + \delta V_i^{k,j}(f(\underline{w}, \underline{\psi}^k(\underline{w})))$$

   Set $V_i^{k+1}(\underline{w})$ to $V_i^{k,m}(\underline{w})$.

4. If $\|V_i^{k+1}(\cdot) - V_i^k(\cdot)\| < \epsilon$ for $i = 1, 2$ then stop; else, set k to $k + 1$ and go to step 2.

A computer implementation of the above algorithm requires an interpolation scheme for the calculation of $V_i^k(y)$ for $y \notin W_h$ and a procedure to compute Nash equilibria of static games in step 2. The convergence of the algorithm may depend to a considerable extent on the choice of these procedures. One possible approach is to choose an interpolation scheme that generates continuously differentiable value functions $V_i^k(\underline{w})$ and then to use equations

$$\frac{\partial R_i(\underline{w}; u_1, u_2)}{\partial u_i} = 0 \tag{21}$$

for $i = 1, 2$, to find equilibria in step 2. More specifically, a cubic spline interpolation scheme *in two dimensions* can be used that provides estimates of $V_i^k(y)$ and of its partial derivatives

$$\frac{\partial V_i^k(w_1, w_2)}{\partial w_i} \tag{22}$$

at $(w_1, w_2) \in W$.

For the problem at hand, the system of equations (21) can be very efficiently solved by a fixed point iteration. Newton's method is another obvious choice. Its value in the given context is limited, however, by the fact that it uses second derivatives of functions $V_i^k(x)$, whose estimates provided by the interpolation tend to be rather inaccurate.

The computational scheme described above turned out to work quite well for the dynamic game considered in this paper. It should be noted, however, that the algorithm is not guaranteed to converge in general and may fail to converge for some combinations of parameters of the model. When the algorithm does converge, it generates feedback strategies $\underline{\psi}$ and value functions V_i, $i = 1, 2$, that satisfy the dynamic programming equations (15), (16) with some given accuracy ϵ.[13]

In general Markov equilibrium may not be unique. In the cases reported in this paper, the uniqueness of the equilibria has been verified by running the algorithm for different initial approximations $V_i^0(\underline{w})$ to the value functions. Nonuniqueness does not seem to be a problem with the models under consideration.

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