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# Foreign direct investment and R&D-offshoring

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We analyse a two-country model of Foreign Direct Investment (FDI) and R&D-offshoring. In the basic model, two firms, each of which is originally situated in only one of the two countries, first decide whether to build a plant abroad. Then, they decide whether to relocate R&D activities offshore. Finally, they engage in product-market competition. In this model, FDI liberalization causes a relocation of R&D activities if intrafirm communication is sufficiently well developed, external spillovers are substantial, competition is not too strong and foreign markets are not too small. Surprisingly, such a relocation of R&D activities usually nevertheless increases domestic welfare.

JEL classifications: F23, O30.

## 1. Introduction

This paper analyses the determinants of multinational firms' choices of locations for production and R&D. We start from a set of stylized facts:

*Stylized Fact 1* Most of the private-sector R&D is done by multinational firms.

Global business R&D expenditure in 2002 amounts to \$450 billion, of which at least two thirds are carried out by multinationals (UNCTAD, 2005). Importantly, R&D offshoring is gaining pace:

*Stylized Fact 2* Multinationals increasingly move R&D offshore.

The global R&D expenditure of foreign affiliates amounted to \$30 billion in 1993 and \$67 billion in 2002 (UNCTAD, 2005). While the share of foreign affiliates in total business R&D is still not very high, it is increasing rapidly.<sup>1</sup> This mirrors

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<sup>1</sup>For similar statements, see Caves (1996, ch.7), Florida (1997), Kuemmerle (1999), Belderbos (2001), von Zedtwitz and Gassmann (2002), Belderbos (2003).

a broader pattern concerning international service outsourcing. While the share of business services produced abroad is still very low, it has grown substantially recently (Amiti and Wei, 2004).

A large empirical literature investigates what kind of locations are likely to be hosts of R&D offshoring. The findings are summarized as follows.<sup>2</sup>

*Stylized Fact 3* R&D by foreign affiliates is attracted particularly to

- (i) large markets and markets with high *per capita* income;
- (ii) locations where the firms have manufacturing and sales activities;
- (iii) countries with large technological know-how (technology sourcing).

Part (iii) reflects the fact that firms are increasingly using knowledge generated in their international subsidiaries as an input to home-country production. Thus, foreign R&D is often accompanied by technology sourcing. For instance, this influenced the location decisions of Japanese firms in the US (Kogut and Chang, 1991). More generally, the importance of technology sourcing has been documented in many empirical papers.<sup>3</sup>

In spite of their growing importance, R&D offshoring and technology sourcing have hardly been analysed theoretically. Important questions are:

- (i) What circumstances favor offshoring and technology sourcing?
- (ii) What are typical characteristics of R&D host countries?
- (iii) How are multinational firms' choices of production locations influenced by considerations concerning R&D locations?
- (iv) What are the welfare effects of R&D offshoring?

We analyse these issues in a simple model which is designed to capture the above stylized facts, in particular, 2 and 3. There are two countries and two firms, each of which is originally situated in only one of the two countries. In Stage 1, firms decide whether to build one plant in the foreign country.<sup>4</sup> In Stage 2, they decide whether to relocate cost-reducing R&D activities offshore and, in stage 3, they engage in product-market competition. Following Marshall (1920), there are external locational knowledge spillovers: if firms carry out R&D in the same location, knowledge flows from one firm to the other, for instance, because employees change firms, or because informal contacts are more likely. As a result, the cost reduction is greater than if each firm innovates in an isolated location.<sup>5</sup>

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<sup>2</sup> See, for example, Zejan (1990), Belderbos (2001, 2003).

<sup>3</sup> Relevant studies include: Cantwell and Hodson (1991), Håkanson and Nobel (1993), Neven and Siotis (1993), OECD (1994), Baily and Gersbach (1995), Almeida (1996), Florida (1997), Kuemmerle (1997), Branstetter (2006), Frost (2001), and Griffith *et al.* (2004).

<sup>4</sup> We are abstracting from the possibility of multiple subsidiaries.

<sup>5</sup> As usual in the literature, we model the extent of external spillovers as an exogenous parameter. In Gersbach and Schmutzler (2003a,b), however, we show how spillovers can be endogenized in a wage-bidding game.

In principle, cost reductions generated in the parent firm also accrue to the subsidiary, and vice versa. However, we assume that there are (usually small) imperfections in the internal knowledge flows in both directions. Thus, a cost reduction in the parent firm will possibly lead to a smaller cost reduction in the subsidiary and vice versa.

Therefore, FDI has a dual role: apart from market access, it allows for technology sourcing which requires that firms move to R&D centres where they have to build up absorptive capacity of their own to benefit from spillovers. The knowledge obtained in these R&D centres is transferred to the home countries, where it reduces costs and thus increases profits. For instance, in the financial service industry, London has emerged as the dominant research centre in Europe. Similarly, in the computer industry, many foreign firms moved parts of their R&D activities to Silicon Valley to benefit from the presence of their North-American competitors.

We obtain the following answers to the four questions posed above: first, FDI liberalization may induce R&D offshoring when intrafirm communication is sufficiently strong, product-market competition is sufficiently weak, and external spillovers are sufficiently strong. Surprisingly, however, there are potential non-monotone effects of improving intrafirm communication and higher external spillovers on the extent of FDI. Second, compared to a setting without the possibility of R&D relocation, FDI becomes more attractive. Third, offshoring usually increases domestic welfare since it only occurs if intrafirm communication is well developed and therefore knowledge generated and obtained abroad flows back to the domestic country. Fourth, though there are also conceivable countereffects, large markets are particularly attractive as R&D hosts because the knowledge generated in the subsidiaries can then also be used to improve competitiveness in those markets.

The R&D decisions of multinationals have been examined by other authors; to our knowledge, however, none of them treats FDI and R&D locations as jointly endogenous, except for our earlier paper (Gersbach and Schmutzler, 1999). The spillover technology we use in the present paper, with both intrafirm and interfirm spillovers, goes back to this earlier contribution. However, the original paper addressed very different questions.<sup>6</sup> Building from the model of spillovers introduced in Gersbach and Schmutzler (1999), Belderbos *et al.* (2008) provide a theory of R&D locations, but treat FDI as exogenous.<sup>7</sup> Papers such as Lin and Saggi (1998), Siotis (1999), Petit and Sanna-Randaccio (2000), Norbäck (2001), Glass and Saggi (2002), Bjorvatn and Eckel (2006), Sanna-Randaccio and Veugelers (2007), and Dawid *et al.* (2008) discuss FDI decisions in their relation to innovation and spillovers, without considering offshoring.

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<sup>6</sup> In a setting with Bertrand competition, we asked under which circumstances multi-plant firms produce in some joint location so as to benefit from technology sourcing.

<sup>7</sup> These authors concentrate exclusively on choices of R&D locations, assuming that both firms operate in both markets. Also, welfare issues are not treated. Whereas we take one polar case (namely that a firm's R&D can only occur in one location), Belderbos *et al.* (2008) emphasize the other polar case that R&D is perfectly divisible across locations. Moreover, they allow for asymmetries between firms.

Section 2 introduces the model. In Section 3, we analyse the equilibria of the R&D location game. Section 4 calculates the subgame perfect (FDI) equilibria. Section 5 provides more specific results for a Cournot example. Section 6 discusses welfare effects. Section 7 extends the game to asymmetric countries. Section 8 contains a more general robustness discussion with various extensions of our model. Section 9 concludes and sketches some generalizations of the model.

## 2. The model

### 2.1 Stages of the game

Consider the following three-stage game. There are two firms,  $k = 1, 2$ , and two countries,  $s = 1, 2$ . Initially firm 1 has a plant in country 1, and firm 2 has a plant in country 2. The firms' actions can be summarized as follows:

Stage 1: firms decide whether to carry out FDI or not (FDI stage).

Stage 2: firms choose R&D locations (offshoring stage).

Stage 3: product-market competition takes place.

In Stage 1, each firm decides whether to become multinational, that is, whether to build an additional plant in the country where it has no production facilities, at a fixed cost of  $F > 0$ . In Stage 2, firms decide whether to continue to carry out their R&D activities (or 'innovate') at home ( $H$ ) or whether to relocate them abroad ( $A$ ). Relocation involves fixed costs  $R > 0$ . In the basic version of our model, we make two simplifying assumptions. First, we assume that relocation (or 'offshoring') is only possible if the firm has carried out FDI.<sup>8</sup> Second, in case of relocation, the R&D location at home is closed.<sup>9</sup> Each firm therefore has exactly one location where it performs R&D, and relocation is treated as a zero-one decision. The assumptions will be relaxed in Sections 8.1 and 8.4, respectively.<sup>10</sup>

### 2.2 Cost structure

Two important considerations are assumed to influence the cost structure:

- (i) External spillovers: when both firms carry out R&D in the same country, they benefit from external knowledge spillovers which allow them to produce at lower marginal costs than if they carry out R&D alone.

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<sup>8</sup>This is consistent with item (ii) in Stylized Fact 3 that firms tend to locate R&D near production.

<sup>9</sup>Of course, this decision could be endogenized. Intuitively, firms will not have two R&D locations if either the fixed costs of maintaining both locations are high or if intrafirm communication is sufficiently well developed. We assume that duplication of R&D is not profitable, which puts a lower bound on the cost of duplication of R&D and the strength of intrafirm knowledge transfer.

<sup>10</sup>The first of these two items is consistent with item (ii) in Stylized Fact 3 that firms tend to locate R&D near production. However, in principle, R&D without manufacturing is also conceivable.

The assumption that external spillovers only arise in locations where both firms have R&D activities is plausible if absorbing knowledge that is relevant for R&D requires the local presence of qualified personnel.

- (ii) Intrafirm knowledge transfer: knowledge generated in the parent firm is useful in subsidiaries (and vice versa), but the resulting cost reduction from R&D is usually not as large as in the location where the knowledge is generated.

As intrafirm knowledge transfer helps to avoid duplication in research efforts, it has long been recognized as a reason for the emergence of multinational firms (Dunning, 1981; Caves, 1996).<sup>11</sup> There are many reasons why intrafirm communication might not be perfect, however. Obviously, there could be costs of communication between different plants and costs of intrafirm labour mobility. There might also be incentive problems: if managers of different plants are rewarded according to relative performance schemes, they may not be willing to release all relevant information.

The existence of external spillovers and (imperfect) intrafirm knowledge transfer translates naturally into the following assumptions about marginal costs, which are assumed to be constant. As a reference cost level  $h$ , it is convenient to use production costs in the absence of R&D. The maximal cost reduction  $\Delta$  relative to  $h$  is obtained in locations where both firms are present with their R&D activities, so that (i) there are external spillovers and (ii) knowledge can be used locally, that is, without transferring it between parents and subsidiary or vice versa. The cost structures in all possible cases are thus given as follows:

- (i) Suppose there is a location  $i$  where both firms are present with their R&D activities (and with FDI as a precondition for R&D). Then
  - (a) marginal costs in  $i$  are  $h-\Delta$  for both firms, because the firms both benefit from knowledge spillovers and there are no losses from internal transfer of knowledge.
  - (b) marginal costs in location  $j \neq i$  are  $h-\gamma\Delta$  for some  $\gamma \in (0,1)$ : a fraction  $(1-\gamma)$  of the cost reduction in location  $i$  is lost due to internal knowledge transfer to  $j$ .
- (ii) Suppose there is no location  $i$  where both firms are present with their R&D activities, and thus no external spillovers occur. Then
  - (a) marginal costs in a firm's R&D location are given as  $h-\beta\Delta$  for some  $\beta \in (0,1)$ . The firm does not benefit from external spillovers; it has to rely exclusively on knowledge it has generated locally.
  - (b) marginal costs in a location without own R&D are  $h-\beta\gamma\Delta > 0$ : the firm does not benefit from external knowledge spillovers and has to rely on knowledge it has generated elsewhere.

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<sup>11</sup> See Baily and Gersbach (1995) for some evidence.

Costs are thus lowest in case (i)(a) and highest in (ii)(b).<sup>12</sup> The ranking between the costs in cases (i)(b) and (ii)(a) (that is, the relative size of  $\beta$  and  $\gamma$ ) depends on whether internal knowledge transfer is more effective than external spillovers. For low values of  $\beta$ , external spillovers are essential for cost reduction, because the difference between costs without and with spillovers is  $h-\beta\Delta-(h-\Delta) = (1-\beta)\Delta$ .

In Stage 3, both firms take production decisions, with marginal costs determined as above. Markets are segregated, that is, we consider only non-tradeable goods or services; but we will extend the discussion to tradeable goods in Section 8.2.<sup>13</sup> Depending on the locations of production and R&D, possible product market profits in one location are denoted by

$$\Pi^M(\beta), \Pi^M(\gamma), \Pi^D(1, 1), \Pi^D(\gamma, \gamma), \Pi^D(\beta, \beta\gamma), \Pi^D(\beta\gamma, \beta),$$

using the following conventions:  $\Pi^M$  stands for a monopoly profit;  $\Pi^D$  for a duopoly profit. The entries in brackets stand for cost reductions relative to  $h$ :  $\beta$  corresponds to  $h-\beta\Delta$ ,  $\gamma$  corresponds to  $h-\gamma\Delta$ , etc. When there are two entries, the first one corresponds to the firm whose profits we are considering, the second one to the competitor. For example,  $\Pi^D(1,1)$  corresponds to the profits of firms in a research centre,  $\Pi^D(\beta, \beta\gamma)$  to the duopoly profit of a firm in its home country when there is no offshoring. Finally, we simplify  $\Pi^D(1,1)\equiv\Pi^D(1)$ ,  $\Pi^D(\gamma,\gamma)\equiv\Pi^D(\gamma)$ .

Assuming that the unique equilibrium is played in the product market stage, the game can be reduced to the first two stages, that is, to the choice of production and innovation locations. The following assumption gives very weak conditions on the nature of oligopolistic interaction.

*Assumption 1* (a) Duopoly profits are decreasing in own costs and increasing in competitor costs, and (b)  $\Pi^D(\gamma)$  is increasing in  $\gamma$ , and  $\Pi^D(\gamma) < \Pi^D(1)$ .

Part (a) is satisfied in standard oligopoly models; part (b) is satisfied whenever the positive effect of lower own costs on profits dominates over the negative effect of lower competitor costs. This requires very reasonable assumptions on demand elasticities (Shapiro, 1989).

### 3. The offshoring subgames

There are offshoring subgames with one and two direct investors.

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<sup>12</sup> Nevertheless, in case (ii)(b) costs are still lower than in the hypothetical case without R&D.

<sup>13</sup> The service sector and the non-tradeable manufacturing sector comprise about two thirds of the economy in industrialized countries, and both FDI and R&D are becoming increasingly important in these industries (Neven and Siotis, 1993; Hackmann, 1997). For example, for banking and finance, business consulting, general merchandising and telecommunications, FDI is the main form of globalization.

### 3.1 Subgames with one investor (asymmetric FDI)

Only the direct investor takes an offshoring decision. With offshoring, this firm obtains payoffs  $\Pi^M(\gamma) + \Pi^D(1) - F - R$ ; without, its payoffs are  $\Pi^M(\beta) + \Pi^D(\beta\gamma, \beta) - F$ . Therefore, we obtain:

*Remark 1* Suppose there is only one direct investor. Then there is an equilibrium where this firm chooses offshoring if and only if

$$\Pi^M(\gamma) + \Pi^D(1) \geq \Pi^M(\beta) + \Pi^D(\beta\gamma, \beta) + R. \quad (1)$$

Clearly, low relocation costs ( $R$ ) favor offshoring. Surprisingly, however, at this level of generality, the effects of the remaining parameters are still ambiguous. For instance, both sides of (1) are increasing in  $\gamma$ , so that it is not obvious whether improved communication leads to more offshoring. Intuitively, as communication improves, knowledge generated offshore leads to high monopoly profits at home, but also to high duopoly profits abroad. However, the first effect would appear to dominate; at least the Cournot example in Section 5 confirms that offshoring becomes more likely as communication improves. Similarly, with better external spillovers (lower  $\beta$ ), not engaging in offshoring means foregoing greater cost reductions, as  $\Pi^M(\beta)$  is increasing in  $\beta$  and  $\Pi^D(\beta\gamma, \beta)$  in the first argument. However, lower  $\beta$  also means that the competitor's costs without offshoring are higher; so that  $\Pi^D(\beta\gamma, \beta)$  is not necessarily increasing in  $\beta$ . Again, in our Cournot example, the offshoring equilibrium is more likely for lower  $\beta$ .

### 3.2 Subgames with two investors (symmetric FDI)

The payoffs for this subgame are given in Table 1. Clearly, there is a 'chicken' structure in the relocation game, with each firm preferring the other one to move: While product market profits are the same for both firms, the firm that carries out R&D offshore has to bear the relocation costs (see Table 1). The subgame equilibria can therefore be characterized as follows.

*Remark 2* Suppose both firms have carried out FDI. If

$$\Pi^D(\gamma) + \Pi^D(1) \geq \Pi^D(\beta, \beta\gamma) + \Pi^D(\beta\gamma, \beta) + R, \quad (2)$$

there are two pure-strategy equilibria,  $(A, H)$  and  $(H, A)$ . Thus, the equilibria involve offshoring. If the sign in (2) is reversed, then there is an offshoring equilibrium  $(H, H)$ .

Several comments are in order. First, for low relocation costs, the equilibrium  $(H, H)$  coexists with another, rather implausible, equilibrium where both firms relocate abroad  $(A, A)$ . Second, with symmetric FDI, offshoring equilibria require that competition is not too intense; otherwise firms differentiate each other in terms of R&D locations to soften competition.<sup>14</sup> Third, by (2), offshoring requires

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<sup>14</sup> As competition becomes very intense, the left-hand side of (2) approaches zero, so that the condition cannot hold.



**Table 1** Subgame with symmetric FDI

	H	A
H	$\Pi^D(\beta, \beta\gamma) + \Pi^D(\beta\gamma, \beta) - F$	$\Pi^D(1) + \Pi^D(\gamma) - F$
A	$\Pi^D(\beta, \beta\gamma) + \Pi^D(\beta\gamma, \beta) - F$	$\Pi^D(1) + \Pi^D(\gamma) - F - R$
	$\Pi^D(\gamma) + \Pi^D(1) - F - R$	$\Pi^D(\beta, \beta\gamma) + \Pi^D(\beta\gamma, \beta) - F - R$
	$\Pi^D(\gamma) + \Pi^D(1) - F$	$\Pi^D(\beta, \beta\gamma) + \Pi^D(\beta\gamma, \beta) - F - R$

external spillovers to be large relative to relocation costs, so that one firm is willing to bear the cost of offshoring to benefit from spillovers.<sup>15</sup> Fourth, the effects of improving communication are again ambiguous: by Assumption 1, as  $\gamma$  increases, so does  $\Pi^D(\gamma)$ . Intuitively, improving communication increases home profits for a firm that offshores. However,  $\Pi^D(\beta\gamma, \beta) + \Pi^D(\beta, \beta\gamma)$ , the total profits of a firm that does not offshore, could increase too. Even though a firm that does not offshore faces tougher competition at home from the competitor that uses knowledge generated abroad ( $\Pi^D(\beta, \beta\gamma)$  decreases as  $\gamma$  increases), it can also compete more effectively abroad, using knowledge generated at home ( $\Pi^D(\beta\gamma, \beta)$  increases). Again, our numerical example will suggest that nevertheless improvements in communication tend to induce offshoring.

### 4. Subgame-perfect equilibria

To understand under which conditions offshoring takes place along with FDI, we now analyse the subgame-perfect equilibria. The preceding analysis suggests that we should distinguish between different parameter regions, according to the outcome of the R&D game.

- (i) LRC (‘low relocation costs’): if (1) and (2) both hold, offshoring obtains no matter whether one or two firms have carried out FDI.
- (ii) HRC (‘high relocation costs’): if (1) and (2) are both violated, there is no offshoring in either type of subgame.
- (iii) MRC (‘medium relocation costs’): if (1) holds, but (2) does not, offshoring only takes place if one firm has carried out FDI.<sup>16</sup>

In regime LRC, relocation costs are so low that there is offshoring in any subgame with FDI. This immediately rules out all equilibria except for the following three.

<sup>15</sup> Clearly, if  $\beta = 0$ , that is, R&D complementarities are essential for cost reduction, (2) will always hold for  $R = 0$ ; for  $\beta \neq 0$ , this is not true in general.

<sup>16</sup> In the numerical example below, it will turn out that (1) typically holds whenever (2) does. We shall thus refer to the case as MRC (‘medium relocation costs’) and ignore the case that (2) holds, but (1) does not. This case is similar to analyse as the MRC case.

*Proposition 1* In regime LRC:

- (i) The no-FDI equilibrium exists if and only if:

$$\Pi^M(\beta) \geq \Pi^M(\gamma) + \Pi^D(1) - F - R. \quad (3)$$

- (ii) The symmetric FDI equilibrium (with offshoring) exists if and only if:

$$\Pi^D(\gamma) - F - R \geq 0. \quad (4)$$

- (iii) The asymmetric FDI equilibrium (with offshoring) exists if and only if conditions (3) and (4) hold with  $\geq$  replaced with  $\leq$ .

Condition (3) guarantees that the no-FDI equilibrium profit is higher than the profit in the deviation subgame, which involves offshoring in LRC. For the symmetric FDI equilibrium, (4) makes sure both firms want to invest, bearing in mind that, in LRC, the competitor would relocate in the equilibrium of the deviation game.

In the MRC regime with intermediate relocation costs, the equilibria are different, as a symmetric equilibrium with both firms investing cannot involve offshoring. As in LRC, however, equilibria with symmetric FDI, with asymmetric FDI and without FDI all arise. The Appendix gives the conditions under which each equilibrium arises.

In the HRC regime, R&D offshoring does not take place in any subgame. Thus, the only issue for firms is whether FDI is worthwhile, that is, whether  $\Pi^D(\beta\gamma, \beta) \geq F$ . If so, the equilibrium involves symmetric FDI; if not, there is no FDI.<sup>17</sup> In the Appendix, the result is stated more carefully.

## 5. The Cournot example

We consider a Cournot example, with linear demand function  $D(p) = a - p$ . We can use standard formulas to calculate equilibrium profits. Throughout this section, we choose  $\alpha \equiv a - h = 1$ ,  $\Delta = 1$ .

### 5.1 The offshoring game

For these choices of  $\alpha$  and  $\Delta$ , the regime in the offshoring game depends on the parameters  $\beta$ ,  $\gamma$  and  $R$ . For sufficiently high relocation costs, there is no offshoring in equilibrium for arbitrary choices of  $\beta$  and  $\gamma$ , so that regime HRC arises.<sup>18</sup> This can be regarded as the benchmark case without the possibility of R&D relocation.

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<sup>17</sup> In the degenerate case where the equilibrium condition holds with equality there is also an asymmetric equilibrium where only one firm carries out FDI.

<sup>18</sup> For our parameterization,  $R = 2$  is sufficiently high for this to happen.

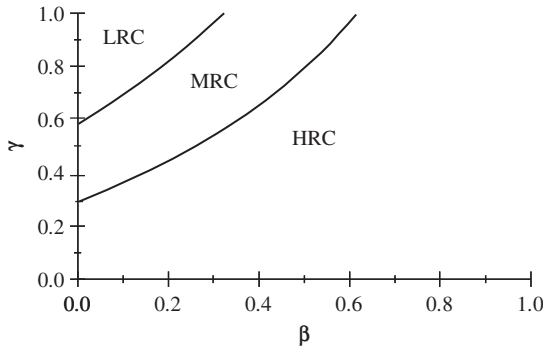


Fig. 1 The offshoring game.

To allow for relocation, we consider  $R = 0.5$ . Figure 1 gives the values of  $\beta$  and  $\gamma$  for which each regime arises.<sup>19</sup>

### 5.2 FDI equilibria

We now describe the subgame-perfect equilibria. We shall compare the benchmark case without relocation ( $R$  very large) with the case that  $R = 0.5$ . In both cases, we shall consider  $F = 1$ ,  $F = 0.5$ ,  $F = 0.2$ , and  $F = 0.1$ .

**5.2.1 No offshoring** Suppose relocation is too costly for arbitrary values of  $\beta$  and  $\gamma$ . For  $F = 1$  and  $F = 0.5$ , no-FDI is the only equilibrium, independent of  $\beta$  and  $\gamma$ . For  $F = 0.1$ , symmetric FDI is the only equilibrium. In the intermediate case  $F = 0.2$ , the equilibrium depends on parameters (see Fig. 2), with (symmetric) FDI arising only for good intrafirm communication ( $\gamma$  high) and effective home R&D ( $\beta$  high). Intuitively, when there is no offshoring, a firm carries out FDI only to gain market access, resulting in profits  $\Pi^D(\beta\gamma, \beta)$ . It relies exclusively on its own R&D, and it must transfer its knowledge abroad to benefit from FDI. When external spillovers are essential and/or intrafirm communication is bad, FDI is not worthwhile.

**5.2.2 Offshoring** Suppose relocation is possible ( $R = 0.5$ ). As before, for  $F = 1$ , no-FDI is the only equilibrium. For  $F = 0.5$ , however, Fig. 3 shows that there is asymmetric FDI when intrafirm communication is very good and external spillovers are essential.<sup>20</sup> One firm engages in FDI and offshoring, so as to benefit from external spillovers. It uses the knowledge obtained to increase its monopoly profit

<sup>19</sup> For lower relocation costs, both regime boundaries would shift further to the right. However, even as relocation costs approach zero, relocation does not necessarily arise for all parameters.

<sup>20</sup> Here and in the following figures, dashed lines describe regime boundaries in the offshoring game.

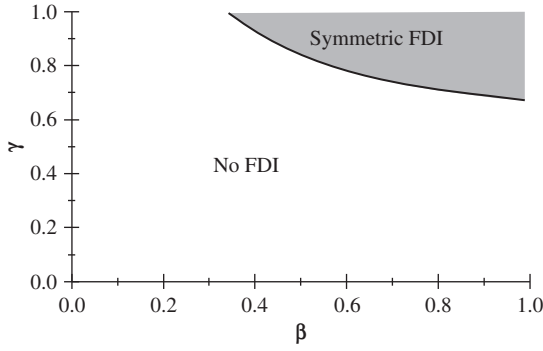


Fig. 2 FDI without offshoring possibilities ( $F=0.2$ ).

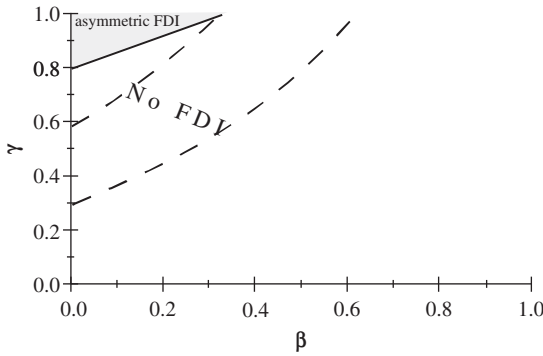


Fig. 3 The FDI game with low relocation costs ( $F=0.5$ ).

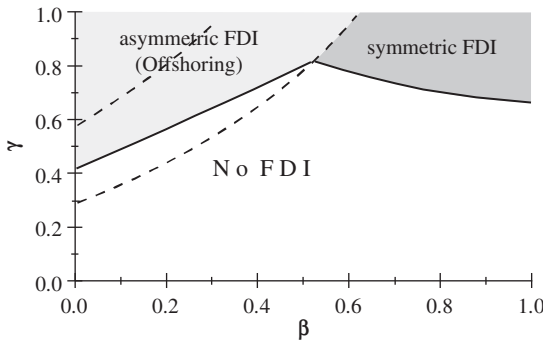


Fig. 4 The FDI game with low relocation costs ( $F=0.2$ ).

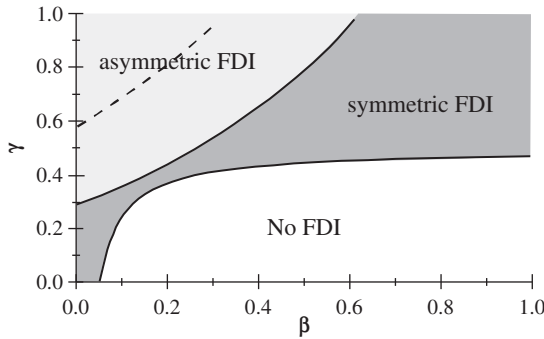


Fig. 5 The FDI game with low relocation costs ( $F=0.1$ ).

abroad. FDI thus requires the offshoring possibility: as we saw above, without offshoring possibilities, no-FDI is the only equilibrium for  $F=0.5$ .

For  $F=0.2$ , Fig. 4 shows that, in the HRC region, for sufficiently good intrafirm communication and internal R&D, there is symmetric FDI, as in the case without offshoring option. Firms do not gain from offshoring, but they can earn sufficient profits in the foreign location even so. In the LRC region and in the MRC region for sufficiently good intrafirm communication and spillovers, there is asymmetric FDI with offshoring in a large region where there was no-FDI without the offshoring option.

For  $F=0.1$ , Fig. 5 shows that, in regime HRC, for sufficiently good internal R&D ( $\beta$  high) and bad intrafirm communication ( $\gamma$  low), there is no FDI. When internal R&D (without spillovers) is already very effective, there is not enough to be gained from FDI, because internal technology transfer is not very good. In intermediate ranges, there is symmetric FDI. In most of this region, this is true even though there is no offshoring and thus no benefit from external spillovers. Internal communication is sufficiently well developed that the foreign location can benefit from cost reductions at home. Finally in most of the LRC and MRC regime, there is an asymmetric FDI equilibrium. The prospects of external spillovers lure one firm into the other country.

### 5.3 Summary

The analysis reveals that the offshoring option makes FDI more likely: for  $F=0.5$ , FDI does not arise without the offshoring possibility, whereas it does for sufficiently low relocation costs.<sup>21</sup> For  $F=0.2$  or  $F=0.1$ , the parameter regions with FDI become larger when offshoring is possible, as a comparison of Fig. 2 with Fig. 4

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<sup>21</sup> We have shown that relocation arises when there are no relocation costs, but by continuity, it also arises for small positive values of  $R$ .

shows. Moreover, asymmetric FDI, with only one firm carrying out FDI and offshoring R&D can arise in a symmetric setting. Moreover, both internal and external spillovers can have non-monotone effects on FDI: for instance, for suitable parameter values higher external spillovers (decreases in  $\beta$ ) lead from symmetric FDI to no-FDI and then to asymmetric FDI (Fig. 4).

## 6. The welfare effects of FDI

The welfare effects of FDI on source countries and recipients have been the subject of considerable debate, and they are often regarded as ambiguous.<sup>22</sup> Based on our analysis, we can obviously not give a complete discussion of this point. Most importantly, welfare discussions of offshoring typically put particular emphasis on the displacement of skilled labour (e.g., job losses of computer programmers in the US as a consequence of software development to India). Our model does not address this topic directly, because labour is only treated implicitly as a cost factor. Several issues could be considered if a broader perspective is adapted. First, when labour markets are flexible, general equilibrium considerations suggest that reducing home country demand by offshoring will reduce wages and thus R&D employees will be reemployed in other sectors. The extent of wage cuts and reemployability depends on how general the skills of displaced R&D workers are. Second, deterioration of home country employment is likely to reduce the willingness to acquire the necessary skills. This could happen if offshoring waves are expected and general equilibrium effects are slow to generate new employment opportunities. In such cases R&D offshoring might even generate outward migration.

In the following, we show that, even ignoring these employment effects, there is an interesting channel by which offshoring affects welfare which is based on knowledge transfer and spillovers.

*Proposition 2* Suppose  $\gamma > \beta$ . Further, suppose the equilibrium involves asymmetric FDI and offshoring by firm 2. Then, welfare in country 2, defined as the sum of consumer surplus and producer surplus, net of fixed costs and relocation costs, is higher than it would be if no firm had invested in FDI. In country 1 the consumer surplus is higher than without FDI, whereas the effect on producer surplus is ambiguous.

*Proof* For an offshoring equilibrium, profits for firm 2 must be higher than in the case without FDI. Thus, a sufficient condition for welfare to increase is that consumer surplus does. As country 2 is served by a monopoly no matter whether offshoring takes place or not, the consumer surplus increases if and only if the costs are lower with offshoring than without. This is true if the cost reduction from

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<sup>22</sup> See Graham and Krugman (1989), Grossman and Helpman (1991), Neven and Siotis (1993), Caves (1996), Sanna-Randaccio (1996), and Markusen and Venables (1997) for an assessment of the arguments.

external spillovers dominates over the cost increase from having to rely on internal communication, that is, if  $\gamma > \beta$ .  $\square$

The assumption  $\gamma > \beta$  makes sure that the home-country cost reduction from technology sourcing outweighs the losses from intrafirm communication. This guarantees that home-country consumers benefit from lower prices. Of course, even if  $\beta \geq \gamma$ , welfare may be higher in an asymmetric offshoring equilibrium than in an equilibrium without FDI, provided the producer surplus is much higher in the former case.

## 7. The impact of market size

The empirical literature suggests that offshoring locations are more likely to emerge in larger markets. We now give theoretical support for this statement, albeit with a qualification. We show that, for certain parameter constellations, the larger country is more likely to emerge as the offshoring location, but there are also conceivable situations where the smaller market is the offshoring host. To understand this, we introduce subscripts  $S$  and  $L$  for profits in the small and large country, respectively. The following assumption captures the essence of market size:

*Assumption 2* (i) For arbitrary cost constellations, profits are larger in the large country, that is  $\Pi_L^M(\cdot) \geq \Pi_S^M(\cdot)$ ,  $\Pi_L^D(\cdot) \geq \Pi_S^D(\cdot)$ .  
(ii) For arbitrary cost constellations, profit increases resulting from lower costs are larger in the large country.

We now ask whether an asymmetric FDI equilibrium is more likely to occur in the large country than in the small country. We confine ourselves to the LRC-regime; with  $R=0$ . Arguing as in Proposition 1, an asymmetric FDI equilibrium in the large country requires

$$\Pi_S^D(\gamma) \leq F, \tag{5}$$

$$F \leq \Pi_L^D(1) + \Pi_S^M(\gamma) - \Pi_S^M(\beta). \tag{6}$$

Condition (5) makes sure that the firm that is located only in the large country does not deviate by adding a plant abroad; inequality (6) guarantees that the firm that carries out FDI and practices R&D-offshoring gains from doing so rather than refraining from FDI. An asymmetric FDI equilibrium in the small country requires

$$\Pi_L^D(\gamma) \leq F, \tag{7}$$

$$F \leq \Pi_S^D(1) + \Pi_L^M(\gamma) - \Pi_L^M(\beta). \tag{8}$$

Clearly, condition (5) for an equilibrium in the large country is easier to satisfy than the corresponding condition (7) for the small country: for the non-investor, deviating from an asymmetric FDI equilibrium in a large country by investing in the small country is less attractive than deviating from an asymmetric FDI equilibrium in a small country by investing in the large country. Hence, the conditions for the

asymmetric equilibrium are easier to satisfy when the large country is the research location provided (8) implies (6), that is,

$$\Pi_L^D(1) - \Pi_S^D(1) \geq \Pi_L^M(\gamma) - \Pi_L^M(\beta) - (\Pi_S^M(\gamma) - \Pi_S^M(\beta)). \quad (9)$$

The left-hand side is always positive, as the firm that carries out FDI and offshores R&D has higher duopoly profits in a large location. If  $\beta > \gamma$ , the right-hand side is negative. Since it is cheaper to serve the monopoly location with own home country R&D than by sourcing from abroad, there is a second reason why an R&D location in a large country is more robust than in a small country: the losses from not serving the monopoly with local R&D are smaller when the monopoly location is small. Thus (9) holds and offshoring into the large country is more likely.

If  $\gamma > \beta$ , however, the right-hand side of (9) is also positive by part (ii) of Assumption 2: when the R&D location is large, the offshoring firm benefits less from the positive R&D effects in its (small) home country monopoly. Therefore, the equilibrium conditions are not necessarily easier to satisfy in the large country. Indeed, consider a scenario where product-market competition in each market is very strong (e.g., close to homogeneous Bertrand competition) and thus (9) is violated.<sup>23</sup> Then, product-market profits in both countries are essentially zero, and thus so is the left-hand side of (9). The right-hand side, however, can be very large in absolute value. Intuitively, in this setting, market access is no reason for FDI and offshoring, whereas technology sourcing is. Therefore, compared to an R&D centre in a large country, a centre in the small country has the advantage that the gains in the monopoly location are larger, and essentially no disadvantage.

## 8. Extensions

We now extend the basic model in several directions. First, we allow for offshoring in locations where the firm is not present with production. Second, we consider finite transportation costs. Third, we shall vary the timing of the game. Finally, we allow for partial rather than complete R&D offshoring.

### 8.1 Offshoring without FDI

If we modify the basic model by assuming that offshoring is possible for both firms at cost  $R > 0$  for arbitrary investment decisions, the offshoring and the FDI decision are decoupled: because access to knowledge does not require the presence of a production location, firms carry out FDI if and only if the resulting duopoly profits in the foreign country justify the fixed costs.

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<sup>23</sup> By ‘strong competition’, we mean any type of product competition such that  $\Pi_L^D(1)$  is sufficiently low. For instance, think of price competition with goods that are not strongly differentiated.



In Appendix 2, we show in more detail how the analysis has to be modified. For every combination of FDI decisions both players have to decide whether or not to offshore. We show that essentially as before, offshoring takes place in all relevant subgames when intrafirm knowledge flows are good, relocation costs are low and external spillovers are high.

Assuming that these conditions for offshoring are met, we then provide conditions for an equilibrium without FDI, but with offshoring. Consistent with the intuition given above, such an equilibrium exists if and only if  $\Pi^D(1) \leq F$ . When offshoring without FDI is possible, the only motive for FDI is market access to the foreign country. In the basic model, there was an additional incentive for FDI, namely to obtain the option of offshoring and thereby gain access to external spillovers which increase home country profits. Net of relocation costs, this option is worth  $\Pi^M(\gamma) - \Pi^M(\beta) - R$ .<sup>24</sup> Whenever this expression is positive, the no-FDI equilibrium arises for a larger parameter region than in the basic model.

While FDI typically becomes less attractive for firms than in the basic model, the welfare effects for the home country are still positive whenever offshoring arises: firms only move R&D offshore when it is profitable for them, and consumers benefit from the cost reduction.

Decoupling of offshoring and FDI decisions allows us to consider another variant of our model, namely that R&D offshoring precedes FDI. This analysis is very similar to the analysis in this section, as the only motive for FDI is market access to the foreign country while R&D offshoring enables access to external spillovers. All qualitative conclusions regarding the emergence of offshoring and FDI remain as before.

## 8.2 Tradable goods

For convenience, we ignored the possibility of finite transportation costs so far, thus focussing on the case that exports are never an alternative. In the following, we modify the basic model (where offshoring requires foreign production) by considering low transportation costs such that firms have no reason to carry out FDI unless they benefit from spillovers. We denote the transportation costs per unit of the commodity by  $t$  and for definiteness, we set  $t = 0$ .<sup>25</sup> Thus, the quality of intra-firm communication is irrelevant for FDI and offshoring decisions, as goods can be exported from wherever they are produced most cheaply to the other country at zero cost.

When only one firm has chosen FDI, it will relocate R&D offshore if and only if

$$2\Pi^D(1) - 2\Pi^D(\beta) - R \geq 0. \quad (10)$$

<sup>24</sup> See Condition (3) in Proposition 1 of the paper.

<sup>25</sup> In Appendix 3, we shall show that similar results hold for intermediate transportation costs such that exports will always take place in the absence of FDI, that is, when the market cannot be served locally, but not when the firm is present locally.

Both firms obtain identical profits  $\Pi^D(1)$  in both locations. After deviation to no-FDI, both firms will produce in their home location, resulting in profits  $\Pi^D(\beta)$  for each firm in each location.

We now assume that (10) holds, so that relocation will take place in the offshoring game. The condition for an equilibrium without FDI then becomes

$$F \geq 2\Pi^D(1) - 2\Pi^D(\beta) - R. \quad (11)$$

There is no FDI if the net gains from offshoring are dominated by the fixed costs. One might think that, with finite transportation costs, FDI is less attractive than with infinite transportation costs, because exports are always an option which would yield foreign profits of  $\Pi^D(\beta) \geq 0$ . However, the condition under which (11) is more easily fulfilled than (3) is

$$\Pi^D(\beta) \geq \Pi^M(\beta) - \Pi^M(\gamma) + \Pi^D(1) - \Pi^D(\beta).$$

The FDI incentives in the case of infinite transportation costs differ from those with zero transportation costs not only because they include the foreign country profits  $\Pi^D(\beta)$ . In addition, for infinite transportation costs, FDI changes home country profits by  $\Pi^M(\gamma) - \Pi^M(\beta)$ , for zero transportation costs the effect is  $\Pi^D(1) - \Pi^D(\beta)$ . However, at least when internal knowledge flows are sufficiently good (so that  $\gamma$  is close to 1), the effects should typically be mutually reinforcing. A cost reduction by a certain amount for a monopolist is worth more than a simultaneous cost reduction of both firms in an oligopoly. Hence, with well-developed internal communication, the intuition that FDI is less attractive with low transportation costs than with infinite transportation costs holds in our model.

Finally, we note that the home country welfare effects of offshoring remain positive whenever it takes place, because offshoring will only happen when the firms benefit, and consumers also benefit from the cost reduction.

### 8.3 Simultaneous decisions

The main insights still hold if the decisions concerning FDI and R&D are carried out simultaneously. Then, each firm has three possible strategies: no-FDI, FDI without offshoring, and FDI with offshoring. The payoffs for each of the nine resulting strategy profiles can be derived as before. An equilibrium without FDI requires that firms neither deviate to FDI with or without offshoring; hence, conditions (3) and (14) in the Appendix have to hold simultaneously. As before, the equilibrium is likely to arise with high fixed costs and relocation costs and with intense product-market competition, whereas, with bad intrafirm communication and low R&D-spillovers, similar qualifications arise as in the sequential case. Contrary to the sequential case, however, an asymmetric equilibrium with only one firm carrying out FDI and offshoring cannot exist, except for degenerate cases.

An equilibrium with both firms carrying out FDI and one firm offshoring exists, provided condition (2) holds and, in addition,

$$\Pi^D(\gamma) + \Pi^D(1) \geq \Pi^D(\beta, \beta\gamma) + F + R$$

and

$$\Pi^D(\gamma) \geq F.$$

As in the sequential model, the offshoring equilibrium essentially requires parameters to be opposite than for the no-FDI equilibrium.<sup>26</sup>

### 8.4 Partial offshoring decisions

So far, offshoring was a zero-one decision: a firm can either move its R&D abroad, or leave everything at home. This is obviously a polar case. We now move to the other polar case that a firm can choose how to allocate its fixed budgets between the two locations in an arbitrary way.

Thus we allow firms to move some arbitrary fraction  $\lambda_i$  offshore at a cost  $K(\lambda_i)$ . For instance, extending our assumptions on cost reductions for  $\lambda_i \in \{0, 1\}$  linearly to the entire interval  $[0, 1]$ , firm  $i$  obtains a cost reduction

$$(1 - \lambda_i)(\lambda_j + (1 - \lambda_j)\beta) + \gamma(\lambda_i(1 - \lambda_j) + \lambda_j\beta)$$

at home and

$$\gamma(1 - \lambda_i)(\lambda_j + (1 - \lambda_j)\beta) + (\lambda_i(1 - \lambda_j) + \lambda_j\beta)$$

abroad. As an example for how offshoring decisions are made in the continuous setting, consider the subgame where only firm 1 has carried out FDI. Thus, it has a monopoly at home and faces a competitor abroad that must have  $\lambda_2 = 0$ , because it cannot offshore its R&D to foreign locations. Ignoring fixed costs of FDI and relocation, payoffs of firm 1 are

$$\Pi^M((1 - \lambda_1)\beta + \gamma\lambda_1) + \Pi^D(\gamma(1 - \lambda_1)\beta + \lambda_1, (1 - \lambda_1)\beta + \lambda_1) - K(\lambda_1).$$

Denote the arguments of  $\Pi^M$  as  $x$  and of  $\Pi^D$  as  $x_1$  and  $x_2$ . Then, the net marginal benefits of offshoring (increasing  $\lambda_1$ ) are

$$(\gamma - \beta)\frac{d\Pi^M}{dx} + (1 - \beta\gamma)\frac{\partial\Pi^D}{\partial x_1} + (1 - \beta)\frac{\partial\Pi^D}{\partial x_2} - K'(\lambda_1).$$

This term consists of (i) a cost-effect on the monopoly profit (which is positive if external spillovers are strong and intrafirm communication is good); (ii) a positive effect on own duopoly profits resulting from the fact that own costs in the foreign location are lower with more offshoring; (iii) a negative effect on duopoly profits resulting from the fact that the competitor also benefits from external spillovers; and (iv) marginal relocation costs. The optimal level of relocation is obtained by setting the net marginal benefit of relocation equal to zero. The analysis for the case where both firms carry out FDI is similar. In this fashion, one can obtain general

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<sup>26</sup>The only qualification concerns intrafirm spillovers which again have ambiguous effects on the offshoring equilibrium.

comparative-static condition for R&D. For the Cournot model and particular specifications of the relocation costs, different FDI/RDI constellations can be obtained.

## 9. Conclusions

We presented a model of multinational activity that differs from existing work in several respects. Most importantly, we provide the only contribution where FDI and R&D offshoring are both endogenous. The model is set up so that there are potentially two motives for FDI, namely access to markets and to knowledge generated locally.

Our first set of conclusions was derived for the case where (i) transportation costs are infinite and (ii) R&D offshoring can only arise in locations where firms are present with production. We obtained the following results. First, FDI liberalization may lead to R&D offshoring. This requires sufficiently strong intrafirm communication, sufficiently weak product-market competition and sufficiently strong external spillovers. Surprisingly, however, once one moves beyond a simple linear Cournot model, there are potential non-monotone effects of intrafirm communication and external spillovers on the extent of FDI. Second, the possibility of R&D relocation makes FDI more attractive. Third, in our simple short-term partial equilibrium model offshoring usually increases domestic welfare since it only occurs if intrafirm communication is well developed and therefore knowledge generated and obtained abroad flows back to the domestic country.<sup>27</sup> Fourth, though there are also conceivable countereffects, large markets are particularly attractive as R&D hosts because the knowledge generated in the subsidiaries can then also be used to improve competitiveness in those markets.

These conclusions have to be modified when R&D offshoring does not presuppose the existence of production facilities. In this case, there is a decoupling of FDI and offshoring decisions: FDI takes place if and only if the market access motive suffices to justify the fixed costs. When we change the basic model by allowing for the possibility of exports, market access is no longer a strong motive for FDI (at least when transportation costs are very low). Instead, the access to knowledge becomes the dominant motive for FDI. Importantly, however, the welfare-enhancing aspect of offshoring survives both modifications.

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<sup>27</sup> See Graham and Krugman (1989) and Neven and Siotis (1993) for a discussion.

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## Appendix 1: Equilibria for MRC and HRC

We now summarize the equilibrium structure in regime MRC.

*Remark 3* In regime MRC:

- (i) A no-FDI equilibrium exists if and only if

$$\Pi^M(\beta) \geq \Pi^M(\gamma) + \Pi^D(1) - F - R. \tag{12}$$

- (ii) A symmetric FDI equilibrium exists if and only if

$$\Pi^D(\beta, \beta\gamma) + \Pi^D(\beta\gamma, \beta) - F \geq \Pi^D(1). \tag{13}$$

- (iii) An asymmetric FDI equilibrium exists if and only if (12) and (13) hold with signs reversed.

Intuitively, condition (12) makes sure that the profits in the no-FDI case are higher than under deviation to FDI, bearing in mind that the firm would relocate following such a deviation in MRC. (13) guarantees that the investing firm does not want to deviate by not investing.

The equilibrium structure in regime HRC is summarized as follows.

*Remark 4* In regime HRC:

- (i) A no-FDI equilibrium exists if and only if

$$0 \geq \Pi^D(\beta\gamma, \beta) - F. \tag{14}$$

- (ii) A symmetric FDI equilibrium exists if and only if

$$\Pi^D(\beta\gamma, \beta) - F \geq 0. \tag{15}$$

Intuitively, as there can be no R&D offshoring on the equilibrium path or in any deviation subgame, firms earn  $\Pi^D(\beta\gamma, \beta) - F$  in an FDI location. Thus, carrying out FDI is worthwhile if and only if  $\Pi^D(\beta\gamma, \beta) > F$ .<sup>28</sup>

## Appendix 2: Offshoring without local production

We first derive conditions for equilibria with offshoring.<sup>29</sup>

*Proposition 3* When both firms can choose offshoring independent of the production location decisions, the equilibria of the relocation subgames are as follows:

- (i) In the subgame without FDI, there are equilibria with R&D offshoring of one of the firms if and only if

$$\Pi^M(\gamma) - R \geq \Pi^M(\beta). \tag{16}$$

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<sup>28</sup> In the degenerate case that  $\Pi^D(\beta\gamma, \beta) = F$ , there is an asymmetric FDI equilibrium that is not strict.

<sup>29</sup> Also, we ignore the implausible equilibrium where the non-investor relocates R&D offshore.

- (ii) In subgames with asymmetric FDI, there is R&D offshoring of the investor if and only if

$$\Pi^M(\gamma) + \Pi^D(1) - R \geq \Pi^M(\beta) + \Pi^D(\beta\gamma, \beta). \quad (17)$$

*Proof* (i) In the subgame without FDI, payoffs in the proposed equilibrium are given as  $\Pi^M(\gamma) - R$  for the offshoring firm and  $\Pi^M(1)$  for the competitor. If the offshoring firm deviates, its profits are  $\Pi^M(\beta)$ . The condition in (i) guarantees that this deviation is not profitable. For the other firm, deviation to offshoring would lower its payoffs as  $\Pi^M(\gamma) - R < \Pi^M(1)$ .

(ii) In the subgame with asymmetric FDI, payoffs in the proposed equilibrium are given as  $\Pi^M(\gamma) + \Pi^D(1) - F - R$  for the offshoring investor. Deviating to no offshoring would yield profits of  $\Pi^M(\beta) + \Pi^D(\beta\gamma, \beta) - F$ . Condition (17) guarantees that this is not profitable. Equilibrium payoffs for the competitor are  $\Pi^D(1)$ ; deviating to offshoring would yield profits of  $\Pi^D(\beta\gamma, \beta) - R$ . Because  $\Pi^D(\beta\gamma, \beta) \leq \Pi^D(\beta) \leq \Pi^D(1)$ , this is never profitable.  $\square$

The following implication is immediate:

*Corollary 1* Offshoring equilibria exist in the no-FDI and asymmetric FDI subgames if  $\gamma = 1$ ,  $R = 0$  and  $\beta$  is strictly below 1.

We now investigate the implications for the FDI game. We ask under which circumstances FDI arises, focusing on the case where offshoring takes place in the second stage, which is the natural analogue of the case of low relocation costs (LRC) in the basic model.

*Proposition 4* Suppose (16)-(17) hold. An equilibrium without FDI, but with offshoring exists if and only if

$$\Pi^D(1) \leq F.$$

*Proof* Conditions (16)-(17) guarantee that offshoring takes place in the equilibrium subgame and in the subgames where one firm deviates in period 1. In the no-FDI equilibrium, the offshoring firm obtains equilibrium payoffs  $\Pi^M(\gamma) - R$ . Deviation to FDI would yield  $\Pi^M(\gamma) + \Pi^D(1) - F - R$ , anticipating that the deviating firm would still carry out offshoring after the deviation.  $\square$

### Appendix 3: Offshoring with intermediate transportation costs

We now show that the results for the case of zero transportation costs essentially generalize to the case of intermediate transportation costs: more precisely, we make the following assumptions:

*Assumption 3* On the one hand, transportation costs are high enough that locations are served locally whenever possible.



Thus, marginal costs are never lower for a firm if it serves a location from abroad than when it produces locally. This is automatically true in R&D locations of the firm, whether it produces alone there or not. To make sure it is also true in locations where the firm has no R&D, we require  $h - \gamma\Delta < h - \Delta + t$  and  $h - \beta\gamma\Delta < h - \beta\Delta + t$ . It is simple to see that the former condition is harder to fulfill, so that all we require is  $t > \Delta(1-\gamma)$ , i.e., transportation costs are higher than the losses from internal communication.

*Assumption 4* On the other hand, transportation costs are low enough that, even if an exporting firm faces a local competitor, it obtains positive profits in spite of the higher marginal costs.

Thus, even in locations where only one firm is present, there is (asymmetric) duopoly competition resulting in positive profits for both firms. It is simple to show that both conditions can be fulfilled simultaneously in principle, a necessary condition being that competition is not too intense.

In the profit formulas, we write  $\beta^T$  for a firm in a country to which it exports from the home location when it is not an R&D centre. Hence, when there is no research centre, the firms earn profits  $\Pi^D(\beta, \beta^T)$  in their home location and  $\Pi^D(\beta^T, \beta)$  in the foreign country. Similarly, for a firm that exports from a research centre, we write  $I^T$  for its marginal cost  $h-\Delta + t$ . Thus, if there is such a research centre, then profits in the other country are  $\Pi^D(\gamma, I^T)$  for the firm that produces there and  $\Pi^D(I^T, \gamma)$  for the exporter.

Consider the offshoring game when only one firm has chosen FDI. Then this firm will choose offshoring if and only if

$$\Pi^D(1) + \Pi^D(\gamma, I^T) - \Pi^D(\beta, \beta^T) - \Pi^D(\beta\gamma, \beta) - R \geq 0.$$

In the research centre, both firms obtain identical profits  $\Pi^D(1)$ ; in the investor's home location, its profits are  $\Pi^D(\gamma, I^T)$ , because it serves the location locally with knowledge generated abroad in the research centre, whereas the competitor exports to the location from the research centre. After deviation to No Offshoring, the firm will face a competitor at home that serves the location from abroad, resulting in profits of  $\Pi^D(\beta, \beta^T)$ . Abroad it will obtain  $\Pi^D(\beta\gamma, \beta)$  as it serves the foreign country with knowledge generated at home, facing a competitor who produces knowledge locally. Thus, the left-hand side gives the net advantage from offshoring.

We now assume that relocation will take place in the offshoring game, i.e., the preceding condition holds. The condition for an equilibrium without FDI then becomes

$$F \geq \Pi^D(\gamma, I^T) + \Pi^D(1) - \Pi^D(\beta, \beta^T) - \Pi^D(\beta\gamma, \beta) - R. \tag{18}$$

The fixed costs must outweigh the net advantage from FDI and offshoring. It is straightforward to compare (18) to (3). The arguments are similar as for no transportation costs.