POLICY RESEARCH WORKING PAPER 1662

From Learning to Partnership

Multinational Research and Development Cooperation in Developing Countries

Giorgio Barba Navaretti
Carlo Carraro

Do multinationals cooperate in research and development with local firms in developing countries? This paper explores the theoretical underpinnings and provides new empirical evidence of R&D cooperation between firms with asymmetric endowments of knowledge.

The World Bank
International Economics Department
International Trade Division
October 1996

Summary findings

Barba Navaretti and Carraro analyze the determinants of interfirm agreements between industrial and developing countries for research and development (R&D) — that is, between firms with asymmetric endowments of knowledge. They develop a model in which a multinational has two options: (1) setting up a subsidiary and competing with a local firm in a duopoly, or (2) implementing an agreement and sharing monopoly profits. The two firms, if they choose the agreement, may also cooperate in R&D. The model shows that:

- The choice of cooperating in R&D is influenced by the intertemporal preferences of the developing country firm, the relative efficiency in R&D of the two firms, and the extent of knowledge spillovers.
- The choice of cooperating in R&D increases both the profitability and stability of the agreement, stability because it affects the long-term trust between the partners.

The empirical analysis is based on a data set of international arm's length agreements, part of which involve joint R&D. Testing the two-choice model supports some of the key theoretical results and assumptions. R&D agreements are particularly likely to emerge when firms are operating in knowledge-intensive industries (where nontangible assets, like knowledge, are large relative to tangible assets), when the partners have a nonhierarchical contractual relationship (they all contribute to the R&D effort), and when technological asymmetries between home and host countries (as proxies of knowledge endowments of the contracting firms) exist but are not too great.

This paper — a product of the International Trade Division, International Economics Department — is part of a larger effort in the department to examine the impact of foreign direct investments on developing countries. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Minerva Pateña, room N5-048, telephone 202-473-9515, fax 202-522-1159, Internet address mpatena@worldbank.org. October 1996. (32 pages)

From Learning to Partnership: Multinational R&D Cooperation in Developing Countries

Giorgio Barba Navaretti*
(Università degli Studi di Milano, Fondazione Eni Enrico Mattei and Centro Studi Luca d'Agliaño)

Carlo Carraro
(Università di Venezia, CEPR and Fondazione Eni Enrico Mattei)

JEL Classification: F23, Multinational Firm; International Business; O32, Management of Technological Innovation and R&D; L22 Firm Organisation and Market Structure

*This paper was prepared by Mr. G. B. Navaretti while he was a consultant with the International Trade Division.

Table of Contents

1. Introduction

Knowledge is an important determinant of the decision to start production abroad. Both the empirical and the theoretical literature emphasise its role in creating ownership advantages. Indeed, it is a firm specific intangible asset, which can be transferred at a lower cost than other capital assets (Horstman and Markusen 1987). At the same time, its nature as a public good influences the effectiveness and, consequently, the form of its transfer. Many recent empirical studies have now gathered a quite impressive body of evidence about knowledge spillovers from multinational activities to host countries' firms (see Blomstrom and Kokko, 1996 for a comprehensive survey of this literature). Costs of spillovers influence the multinationals' choice of internalised international transactions (subsidiaries), versus arm-length ones (e.g. licensing) (Ethier 1986, Ethier and Markusen 1991).

Transfer of technology is generally characterised as a hierarchical process, where host countries are passive recipient of technologies developed in the home country. This assumption, which is even more stringent when applied to the North-South space, is not consistent with some recent evidence about multinational activity. *First,* R&D activity carried out by multinationals is often geographically dispersed (Cantwell 1993 and 1994, Kumar 1995). *Second,* R&D is often carried out by networks of firms located in different countries, including developing countries (Contractor and Lorange, 1988, Vonortas, 1991, Pietrobelli, 1996). *Third,* aggregate evidence shows that international trade generates R&D spillovers: the larger the share of imports from countries rich in R&D capital, the larger the developing countries' foreign R&D capital and the larger their rate of growth (Coe, Helpman and Hoffmaister, 1995).

Thus, international flows of technology do not necessarily imply unilateral and hierarchical transfers of knowledge. Moreover, the geographical dispersion of R&D activities can take place in a non-internalised way, through co-operative arm length agreements between different firms. Some recent theoretical contributions support this evidence by showing that spillovers may induce R&D co-operation between firms, also when endowments of knowledge across partners are asymmetric (d'Aspremont and Jaquemin 1988, Bhattacharya, Glazer and Sappington, 1990 and 1992, Aghion and Tirole, 1994).

This paper develops a theoretical model which brings together some of the central assumptions of the literature on R&D cooperation and of the literature on hierarchical transfer of technology. It inquires whether R&D cooperation is an effective tool to internalise asymmetric knowledge spillovers in a hypothetical North-South setting. The model examines the R&D cooperation decision jointly with the choice of the institutional format characterising the transfer of technology. The multinational can set up a subsidiary and compete with a local producer. Alternatively it can set up an arm length agreement with the local producer. In the first case we have a duopoly, in the second one a monopoly in the host market. Notice that this simplified setting does not reduce the generality of our results, that would also hold in a more general oligopolistic framework.

The theoretical findings are tested by using a data bank containing 632 inter-firm technological international agreements, where at least one of the partners is located in a developing country[1]. The empirical results, derived by testing a dichotomous choice model, support the major theoretical findings: R&D agreements are particularly likely to take a non-hierarchical format (each partner contributes to the R&D effort), in knowledge intensive industries and when technological asymmetries between home and host countries are not excessively large.

This empirical analysis is very innovative compared to other analysis of international R&D. *First,* because it looks at technological agreements between a group of developing countries and a group of advanced countries, whereas previous works were mostly focused on advanced countries. (Kumar, 1995 gives a useful survey). *Second,* because most of the empirical literature has looked at the R&D activity carried out by subsidiaries, up to now, and not at arm-length agreements (a survey of the very little existing evidence on technological agreements is provided by Pietrobelli, 1996). *Third,* and consequently, because previous works mainly focused on the determinants of localisation of R&D, whereas, here, we can also address institutional features of R&D cooperation at the firm level.

The next section will list the major assumptions underlying the theoretical model. Section three will derive the equilibria about R&D cooperation and the institutional format under which such cooperation takes place. Section four reports the empirical results and section five concludes.

---

[1]. These agreements are a subset of the Cati-Merit data bank. For a description of the data base, see Duysters and Hagedorn, 1993. For a descriptive application to developing countries see Freeman and Hagedorn, 1994. Some of the empirical results reported in this paper can also be found in Barba Navaretti and Bigano, 1996

2. The theoretical model

2.1. Background

The common starting point of the literature on hierarchical transfers of technology (see, for example, Ethier, 1986, Wright, 1993 Ethier and Markusen, 1991) is some R&D activity creating a firm specific asset, which can be a new product, a reduction in production costs or the improvement of product quality. This new knowledge is held by the parent company, who wants to exploit this asset on a foreign market.

This literature examines the choice between arm length contracts (e.g. licensing) and subsidiaries, by looking at the trade off between lower establishment costs and larger spillovers of proprietary knowledge. Licensing does not involve the fixed cost of setting up a new productive unit in a foreign country. However, it engenders larger spillovers. In principle, one would expect that the larger potential spillovers (as measured by the share of knowledge capital on total assets of the firm) the more likely the transfer to be internalised through a subsidiary.

Yet, subsidiaries are not water tight. Spillovers may still arise because the employees of the subsidiary can quit and set up an independent firm (Ethier and Markusen, 1991) or because competitors in the host market manage to learn the trade after a while (Wang and Markusen, 1992). The interesting result of this literature is that the larger the potential spillovers, the larger the amount of knowledge the multinational will transfer to the subsidiary in equilibrium. Intuitively, in the first case, the multinational buys in the employees' loyalty, by granting them a larger share of future expected rents; in the second case, it preserves the competitive edge of its subsidiary, by ensuring that the latter has always a superior technology than local competitors.

The lesson we can draw is that knowledge spillovers can be internalised only through contracts that give the partners a large enough incentive not to defect. A subsidiary, where employees can quit once the learning process is accomplished, raises the same problems than any arm length agreement. Moreover, spillovers across independent firms can only be internalised through knowledge sharing contracts.

If knowledge sharing contracts (including asymmetrical ones) are the only mean to internalise knowledge, there may be circumstances under which the multinational prefers to cooperate in R&D with the local firm. The model developed in this paper examines whether there is ground for R&D cooperation under asymmetrical spillovers and R&D efficiency. The model merges some of the major assumptions of the literature on asymmetrical transfer of knowledge and on R&D joint ventures.

2.2. Structure of the game

We look at the case of a multinational which carries out some R&D which is only related to its activities in the host market. In the host market there is another competing firm, also carrying out some R&D. The multinational can choose between setting up a subsidiary and competing against the local firm (a duopoly) and establishing an arm-length agreement with the local firm and share monopoly profits. If they form the arm-length agreement the two firms can also decide to cooperate in R&D. In the duopoly there is never cooperation in R&D.

The rules of the game can be described as follows. The interactions between the multinational and the developing country firm can be characterised as an infinitely repeated game in which each period is divided into four stages:

- in the *first* stage, the multinational firm decides whether to share the technology with the developing country firm or to produce directly in the developing country, by establishing a subsidiary. In the first case, the agreement is characterised by a contract which specifies the share of profit which are taken by the multinational firm. This share can be viewed as a licence for the use of the technology or as an equity share in a joint venture. If the two firms opt for the subsidiary there are bilateral knowledge spillovers (each firms' R&D creates knowledge spillovers towards the other firm). These spillovers are asymmetric. The developing country firm receives spillovers larger than those received by the multinationals.

- in the *second* stage, if they have opted for the agreement, the two firms decide whether or not to cooperate on the research and development of a process innovation which reduces the production costs of the developing country firm. For simplicity's sake, we assume that innovation is market-specific which implies that the R&D effort carried out by the two firms, either cooperatively or non cooperatively, benefits the production process only of the developing country firm (which is the only producer in the market). The multinational firm achieves an indirect benefit from its R&D effort through its share of profits from the agreement. Notice that R&D cooperation can occur only if the two firms opt for the agreement. If they do not, or if one of the two defects, then market competition takes the form of a non-cooperative duopoly where non-cooperation concerns both output and R&D.

- in the *third* stage, production takes place. As previously stated, the developing country market is a monopoly. This market remains a monopoly if the multinational firm chooses the agreement; it becomes a duopoly if the multinational firm decides to produce directly in the developing country. Therefore, the multinational firm has an incentive to share the technology rather than to produce directly because the first option provides larger profits in the output market (the sum of duopoly profits is lower than the monopoly profit).[2] However, when choosing the agreement the multinational provides larger spillovers to the developing country firm, and also run a risk of defection from the agreement (this risk obviously does not exist in the duopoly case).

- in the *fourth* and final stage, the developing country firm decides whether or not to comply with the agreement. In the latter case, it does not transfer to the multinational firm the agreed share of profits (e.g. it does not pay the licence or it transfers all profits and the technology to a new legal entity). When the developing country firm chooses to defect, the multinational firm reacts by producing directly in the developing country in the following period.

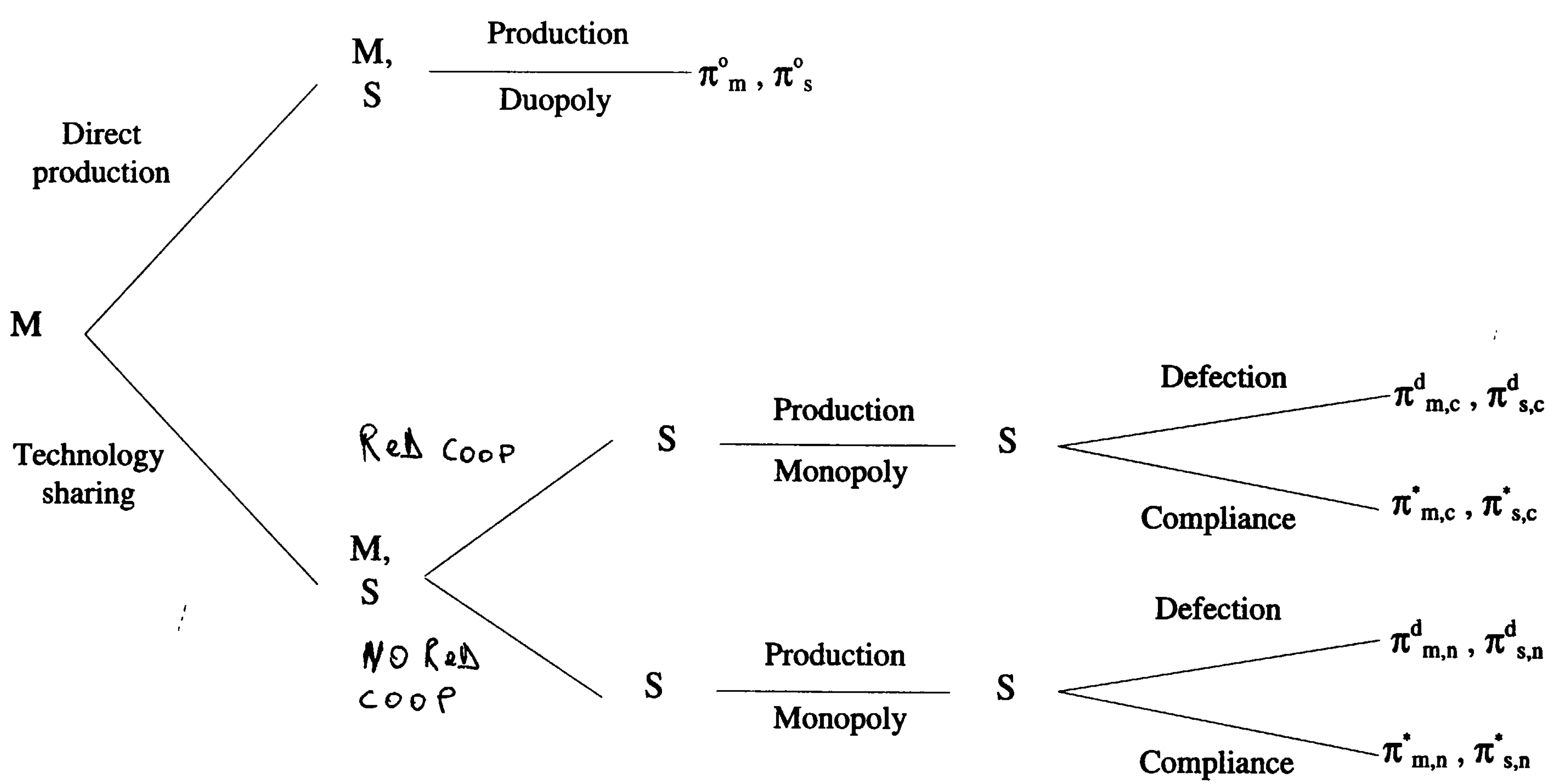
The game tree is described in Figure 1, where the payoffs are as follows. Let *m* denote the Multinational firm and *s* the developing country (Southern) firm, whereas *c* denotes the payoffs when the two firm Cooperate on the development of a process innovation and *n* the payoffs when they carry out their own R&D Non cooperatively.

Then:

- $\pi^{\circ}_{j,i}$, $j=m,s$ and $i=c,n$ are the duopoly Nash-Cournot payoffs that the two firms achieve when the multinational firm decides to produce directly in the developing country.

[2] Again, we re-call that the analysis is confined to the two firm case for simplicity's sake. A more general oligopoly setting would provide qualitatively similar results.

Figure 1: The Game Tree



- $\pi^d_{j,i}$, j=*m,s* and i =*c,n* are the firms' profits when the developing country firm defects in the last stage of a given period of the game;

- $\pi^*_{j,i}$, j=*m,s* and i=*c,n* are the firms' profits when the multinational chooses the agreement and the developing country firm complies with it.

Moreover, let us use the following definitions:

- ε is the share of profits of the developing country firm which are paid back to the multinational when there is no defection ($0 \leq \varepsilon \leq 1$);

- $\alpha \leq 1$, is the discount factor of the developing country firm. A large value of α implies that the southern firm has a low discount rate;

- $x^i_j \geq 0$, i=*c,n* and j=*m,s* is the amount of R&D carried out by the firms; x^i, i=*c,n* denotes the vector (x^i_m, x^i_s);

- $\phi_s \geq \phi_m$, where ϕ_j, j=*m,s* is the parameter which defines the level of the R&D marginal cost. Therefore, we assume that R&D efficiency is generally lower in the developing country.

- $\pi^{\#}_s(x^i) > 0$, i=*c,n* is the monopoly profit obtained by the southern firm, gross of R&D costs and the agreement fee.

Particular attention must be given to our assumptions on R&D spillovers. If the multinational opts for the subsidiary and the market is a duopoly, there are technological spillovers defined by the parameters β_s and β_m, where β_i, i=*s,m* measures the reduction of firm i's production costs induced by a marginal change of R&D expenditure in country j, i,j=*m,s* and i≠j. Moreover, $\beta_s \geq \beta_m$, i.e. the multinational, being technologically more advanced, transfers more knowledge than what it receives. If instead the multinational opts for the agreement, there is one producer only in the market, which receives a spillover equal to $\beta \geq \beta_s \geq \beta_m$ from the multinational's R&D activity. This is so, because the R&D carried out within this particular agreement does not concern the multinational's activities elsewhere. Moreover, it is quite reasonable to assume that the Southern firm learns more from its counterpart under an arm-length agreement than through external interaction in a competitive market, even if R&D is not carried out cooperatively. If this activity is carried out cooperatively, there is full knowledge sharing and the uni-directional spillover is equal to 1. In words, in the cooperative case, both the multinational's R&D and the one carried out by the developing country firm have the same impact on the latter production costs.

The decision variables are as follows: the multinational decides how to sell in the developing country market (technology sharing or direct production), the amount of R&D, and the profit share ε. The developing country firm sets the amount of R&D and the production level, and decides whether or not to comply with the agreement.

Given the above definitions, we have:

(1a) $$\pi^*_{m,i} = \varepsilon[\pi^\#_s(x^i) - (1/2)\phi_s(x^i_s)^2] - (1/2)\phi_m(x^i_n)^2 \qquad i=c,n$$

(1b) $$\pi^*_{s,i} = (1-\varepsilon)[\pi^\#_s(x^i) - (1/2)\phi_s(x^i_s)^2] \qquad i=c,n$$

where we assume decreasing returns to scale in R&D. Moreover:

(2a) $$\pi^d_{m,i} = -(1/2)\phi_m(x^i_m)^2 \qquad i=c,n$$

(2b) $$\pi^d_{s,i} = \pi^\#_s(x^i) - (1/2)\phi_s(x^i_s)^2 \qquad i=c,n$$

In order to solve the game backward, let us now consider the last stage of each period of the game.

2.3. A long term agreement

The developing country firm does not defect in the last stage of a given period of the game if its discounted payoff when it complies with the agreement is larger than its discounted payoff when it defects at period t and then is "punished" by the multinational's decision to produce directly in the developing country. If defection does not take place in the first period, then it will not take place in any other period. Therefore, the no defection condition is:

$$\pi^*_{s,i}/(1-\alpha) \geq \pi^d_{s,i} + \alpha\pi^o_s/(1-\alpha)$$

which implies

(3a) $$\alpha \geq (\pi^d_{s,i} - \pi^*_{s,i})/(\pi^d_{s,i} - \pi^\circ_s) =$$

$$= \varepsilon[\pi^\#_s(x^i)-(1/2)\phi_s(x^i_s)^2]/[\pi^\#_s(x^i)-(1/2)\phi_s(x^i_s)^2-\pi^\circ_s]$$

or

(3b) $$\alpha \geq \varepsilon/[1 - \pi^\circ_s/(\pi^\#_s(x^i) - (1/2)\phi_s(x^i_s)^2)]$$

Notice that this condition is more easily satisfied when the developing country firm's discount rate is low, when the profit share which goes to the multinational is low and when the duopoly payoff for the developing firm is also low.

Recall that ε is a decision variable of the multinational. Therefore, this firm will choose the largest ε such that the developing country firm complies with the agreement, i.e.:

(4) $$\varepsilon = \alpha[1 - \pi^\circ_s/(\pi^\#_s(x^i) - (1/2)\phi_s(x^i_s)^2)] = \alpha[(\pi^d_{s,i}-\pi^o_s)/\pi^d_{s,i}]< 1$$

The equilibrium value of ε does not allow *m* to extract the whole rent from the southern firm. The condition for the developing country firm to agree on technology sharing is:

(5) $$\pi^*_{s,i} \geq \pi^\circ_s \qquad i=n,c$$

i.e. the profit for this firm when it agrees on technology sharing must be larger than its profit when it refuses, that is when the outcome is the duopoly in which both firms produce in the developing country. Therefore, it could be argued that the multinational firm could choose ε in order to meet the participation constraint (5), i.e. ε such that

$$\pi^*_{s,i} - \pi^\circ_s = 0.$$

We can show that this is not true and that, in order to prevent the southern firm from defecting, the multinational must leave some of the rent to the developing country firm, i.e. $\pi^*_{s,i} > \pi$

Condition (3a) can indeed be written as:

(6) $$\alpha \geq (\pi^d_{s,i} - \pi^*_{s,i})/[(\pi^d_{s,i} - \pi^*_{s,i}) + (\pi^*_{s,i} - \pi^\circ_s)]$$

where we have added ad subtracted $\pi^*_{s,i}$. Notice that if $\pi^*_{s,i} = \pi^\circ_s$ we would have $\alpha \geq 1$, which can be satisfied only for $\alpha = 1$, i.e. when the discount rate is equal to zero. This implies that defection in the last stage would be very likely and that the equilibrium choice for the multinational would be the establishment of a subsidiary in the developing country. Therefore, in order to implement an agreement, the multinational must accept $\pi^*_{s,i} > \pi^\circ_s$.

Let $\pi^*_{s,i} - \pi^\circ_s = \theta_{s,i}$ be the part of total profits $[\pi^\#_s(x^i) - (1/2)\phi_s(x^i_s)^2 - \pi^\circ_s] = (\pi^d_{s,i} - \pi^\circ_s)$ which goes to the developing country firm. The part which goes to the multinational is $\theta_{m,i} = \varepsilon[\pi^\#_s(x^i) - (1/2)\phi_s(x^i_s)^2] = \pi^d_{s,i} - \pi^*_{s,i}$; which implies $\pi^d_{s,i} - \pi^\circ_s = \theta_{s,i} + \theta_{m,i}$. Using these definitions, the following proposition can be proved:

Proposition 1: *The share of total profits in the developing country which goes to the Southern firm does not depend on the firms' choice about R&D cooperation, unless the choice of cooperating in R&D affects the discount factor* α. *Hence, R&D cooperation cannot be used as a stabilising factor of the arm length agreement, unless it affects the inter temporal preferences of the Southern firm.*

Proof. Let us first proof that the stability of the arm-length agreement depends on the share of profits which goes to the southern firm. From (6) we can write:

(7) $$\alpha \geq 1/[1 + (\pi^*_{s,i} - \pi^\circ_s)/(\pi^d_{s,i} - \pi^*_{s,i})] = 1/[1 + \theta_{s,i}/\theta_{m,i}] \equiv 1/(1+\sigma_i)$$

where $\sigma_i = \theta_{s,i}/\theta_{m,i}$. Moreover, the share of profits which goes to the developing country firm is $\theta_{s,i}/(\theta_{m,i}+\theta_{s,i}) = \sigma_i/(1+\sigma_i)$. Using the above definitions and the optimal choice of ε defined by (4):

(8) $$\theta_{s,i}/(\theta_{m,i}+\theta_{s,i}) = (1-\alpha)$$

Therefore, given α, the share does not depend on whether or not firms cooperate in R&D. This implies that σ_i is also independent on the firms' choice about R&D cooperation and so is the condition which guarantees the stability of the agreement.

This first result implies that R&D cooperation does not help in stabilising the overall agreement, if the only impact of cooperation is to increase overall monopoly profits. Indeed, even if overall profits increase, equilibrium ε will also increase; i.e. *m* will adjust ε so that *s* keep receiving a constant share of profits net of *s*' reserve duopoly profits $\pi^{\circ}_{s}(\sigma_i)$. In contrast, if R&D cooperation is expected to generate also other future benefits, in the form of spillovers and long-term transmission of tacit knowledge, *s*' inter temporal preferences will change, and α will increase. In this case, σ_i will also increase. We have therefore shown that R&D agreements can stabilise agreements aimed at internalising knowledge spillovers only when they generate intangible benefits deriving from a long term relationship of trust.[3]

Given that the optimal choice of ε lead both firms to comply with the agreement in the last stage of each period of the game, let us move to stage three and two, when the production and R&D investment decisions are taken.

2.4. Optimal production and investment in R&D

Using the optimal value of ε (from 1a and 1b), profits become:

(9a) $$\pi^*_{m,i} = \alpha[\pi^{\#}_{s}(x^i) - (1/2)\phi_s(x^i_s)^2 - \pi^{\circ}_{s}] - (1/2)\phi_m(x^i_m)^2$$

(9b) $$\pi^*_{s,i} = \pi^{\circ}_{s} + (1-\alpha)[\pi^{\#}_{s}(x^i) - (1/2)\phi_s(x^i_s)^2 - \pi^{\circ}_{s}]$$

Notice that π°_{s} is the profit that the southern firm guarantees itself anyway. Therefore, its total profit must be equal to π°_{s} plus the share of additional profits that the multinational leaves to the southern firm in order to stabilise the agreement.

At this stage of the game, only *s* takes a decision, i.e. it sets the optimal production level by maximising $\pi^{\#}_{s}(x^i)$ (the only element of the profit function which depends on output). The usual

[3] This conclusion should not be surprising, given the results obtained in the industrial organisation literature on the profitability and stability of cartels and /or R&D coalitions (Cf. Donsimoni et al., 1986; Motta, 1993). When there are two firms only, the stability of an agreement in a repeated relationship crucially depends on the firms' discount rate. The higher the discount rate, the easier for the agreement to be stable even in the presence of small gains. The problem in our case is that R&D cooperation increases both relative gains and incentives to defect, leaving the ratio unchanged. Therefore, only an increase of the discount rate can increase the stability of the agreement between the two firms. The link between profitability and stability is also discussed in Carraro-Siniscalco (1996).

optimality condition (marginal revenue equal marginal cost) determines the optimal monopoly output (y^*_S). For simplicity, let us use the symbol $\pi^{\#}_S(x^i)$ to denote also the level of profits obtained in the developing country when the production level is optimally chosen.

In order to derive the optimal R&D efforts carried out by the two firms, let us formalise our assumptions on R&D spillovers. In the cooperative case:

$\partial c_S(y^*_S)/\partial x_S = -1$ and
$\partial c_S(y^*_S)/\partial x_m = -\beta > -1$

whereas:

$\partial c_S(y^*_S)/\partial x_i = -1$, $i=s,m$,

in the cooperative case. In words, this implies that:

- R&D concerns process innovation, i.e. a higher R&D level reduces the firms' production costs.
- the spillover on southern firm's costs of the multinational's R&D is equal to β when the two firms do not cooperate in R&D and t is equal to -1 when R&D is carried out cooperatively.

If the multinational decides to produce directly in the developing country, Nash-Cournot payoffs depend on bilateral spillovers, i.e. $\pi^\circ_m = \pi^\circ_m(\beta_m,\beta_S)$ and $\pi^\circ_S = \pi^\circ_S(\beta_m,\beta_S)$, where $\beta_S > \beta_m$, and where $\beta_m < \beta$, $\partial\pi^\circ_i/\partial\beta_i > 0$, $\partial\pi^\circ_i/\partial\beta_j < 0$, $i=m,s$ and $i \neq j$. Notice again that spillovers in the case of agreement are larger than in the case of subsidiary.

We have assumed that spillovers increase when there is cooperation. The literature stresses that much of technological knowledge is not codified, but, rather, it is held in a tacit form. Hence, it can only be transmitted on the job, and when there is a strict interaction between the parties (David, 1993). This assumption differs from the one normally made by the literature on R&D cooperation (Cf. D'Aspremont Jacquemin, 1988), where spillovers do not change if there is cooperation. This is important because the change of spillovers from non cooperation to cooperation is a crucial effect to understand the results on the profitability of R&D cooperation.

Furthermore, spillovers without cooperation (the parameter β) are likely to be larger the larger and the more efficient the learning effort of the Southern firm (which is also partially captured by the coefficient of R&D investments ϕ_S). Spillovers will also be affected (ambiguously) by the degree of knowledge intensity (relative to other tangible and intangible assets) of the firm and the industry concerned by the agreement. On the one hand, the larger the knowledge intensity, the larger the amount of knowledge to spread around. On the other hand, learning is more difficult in knowledge intensive industries.[4]

Using these assumptions, the first order conditions for the optimal choice of R&D are:

<u>No R&D cooperation.</u>

(10a) $$\partial\pi^*{}_m/\partial x_m = \alpha\beta(-\partial\pi\#_s/\partial c_s) - \phi_m x_m = 0$$

(10b) $$\partial\pi^*{}_s/\partial x_s = (1-\alpha)[(-\partial\pi\#_s/\partial c_s) - \phi_s x_s] = 0$$

where we used $\partial\pi^{\#}{}_s/\partial x_i = (\partial\pi\#_s/\partial c_s)(\partial c_s/\partial x_i)$, $i=m,s$, and where $\partial\pi\#_s/\partial c_s < 0$.

<u>R&D cooperation</u>

When the two firms cooperate, they maximise the sum of their profits, i.e. $\pi^*{}_c = \pi^{\#}{}_s(x^i) - (1/2)\phi_s(x^i{}_s)^2 - (1/2)\phi_m(x^i{}_m)^2$. This yields:

(11a) $$\partial\pi^*{}_c/\partial x_m = (-\partial\pi\#_s/\partial c_s) - \phi_m x_m = 0$$

(11b) $$\partial\pi^*{}_c/\partial x_s = (-\partial\pi\#_s/\partial c_s) - \phi_s x_s = 0$$

Therefore, using (10a,b), the non-cooperative R&D levels are implicitly defined by:

(12a) $$x^n{}_m = \alpha\beta(-\partial\pi\#_s/\partial c_s)/\phi_m > 0$$

---

[4] The assumption that spillovers are larger the more knowledge intensive is the industry is standard in the literature on asymmetric transfer of knowledge (see Markusen, 1995 for a survey). The assumption that they are larger the more intense the learning effort of the southern firm can be found, for example, in Wang and Blomstrom, 1992.

(12b) $x^n_s = (-\partial\pi\#_s/\partial c_s)/\phi_s > 0$

where $x^n_m > x^n_s$ iff $1 > \alpha\beta > \phi_m/\phi_s$, i.e. when ϕ_s is sufficiently larger than ϕ_m.

If the two firms cooperate in R&D, their R&D efforts are implicitly defined by:

(13a) $x^c_m = (-\partial\pi\#_s/\partial c_s)/\phi_m > 0$

(13b) $x^c_s = (-\partial\pi\#_s/\partial c_s)/\phi_s > 0$

Notice that $x^c_m > x^c_s$ because $\phi_m < \phi_s$. Moreover:

(14a) $x^c_m > x^n_m$

because $\alpha\beta < 1$. The increased R&D effort of the multinational reduces costs and increases production ($\partial y_s/\partial c_s < 0$). This implies that $(-\partial\pi\#_s/\partial c_s)$ under cooperation is larger than $(-\partial\pi^\#_s/\partial c_s)$ when the two firms do not cooperate in R&D. Indeed, the impact of a change of production costs on monopoly profits can be written as:

$$-\partial\pi\#_s/\partial c_s = (\partial\pi\#_s/\partial y_s)(-\partial y_s/\partial c_s)$$

where y_s is the equilibrium production. Notice that $\partial^2\pi^\#_s/\partial y_s\partial y_s > 0$. As a consequence, both $\partial\pi^\#_s/\partial y_s$ and $-\partial y_s/\partial c_s$ are larger under cooperation. Hence, $-\partial\pi^\#_s/\partial c_s$ is also larger when the two firms cooperate in R&D, which implies:

(14b) $x^c_s > x^n_s$

The same conclusion can be achieved by noticing that R&D efforts are strategic complements. Therefore, equilibrium investments in R&D are larger under cooperation for both the multinational and the southern firm.

2.5 Cooperating in R&D

Is the choice to cooperate in R&D profitable? To answer this question we must compare benefits and costs of R&D cooperation. For the multinational, this yields:

(15a) $$\pi^*_{m,c} - \pi^*_{m,n} = \\ = \alpha[\pi^{\#}_s(x^c) - \pi^{\#}_s(x^n)] - (1/2\phi_m)[H^2_c(1-\alpha^2\beta^2)+(H^2_c-H^2_n)(\phi_m/\phi_s+\alpha\beta^2)]$$

where H_c is the value of $-\partial\pi\#_s/\partial c_s$ under cooperation, whereas H_n is the value of $-\partial\pi\#_s/\partial c_s$ when the two firms do not cooperate in R&D. From the previous discussion $H_c-H_n \geq 0$. The first term of the right-hand side represents the increased monopoly profit obtained by the multinational when the two firms cooperate and increase their R&D efforts, thus reducing costs and increasing profits. The second term represents the cost increase induced by higher R&D spending under cooperation.

For the developing country firm, the comparison yields:

(15b) $$\pi^*_{s,c} - \pi^*_{s,n} = \\ = (1-\alpha)[\pi^{\#}_s(x^c) - \pi^{\#}_s(x^n)] - [(1-\alpha)/2\phi_s](H^2_c-H^2_n)$$

Again, the first term of the right-hand side represents the increased profit that the southern firm obtains when it cooperates (which is lower the higher α), whereas the second term is the increased R&D cost.

Let us assume that firms do not defect from a potential decision to cooperate in R&D (because defection only takes place at the last stage and concerns the whole agreement of which R&D cooperation is one possible feature). Moreover, let us assume that:
- the effects of R&D cooperation on $-\partial\pi\#_s/\partial c_s$ are small with respect to those on the level of profits and R&D costs;
- the effects on profits of a change of R&D efforts are larger than those on total R&D costs.[5]

Then, we have:

[5] This is the case for linear demand and cost functions. See d'Aspremont-Jacquemin (1988).

Proposition 2: *The multinational is more likely to choose to cooperate in R&D with the developing country firm whenever the latter discount rate is low (α is large), the marginal cost of R&D is low (ϕ_m is small), and the spillover β is low. R&D cooperation is profitable when the right-hand side of (15a) is non-negative, i.e. for $\phi_m \leq \phi^*_m$, where ϕ^*_m is implicitly defined by $\phi^*_m = H^2_c[1+\alpha(1-\alpha)\beta^2]/2[\alpha[\pi^{\#}_s(x^c) - \pi^{\#}_s(x^n)] - (H^2_c - H^2_n)/2\phi_s]$. Similarly, the southern firm chooses not to cooperate if the right-hand side of (15b) is non-negative, i.e. $\phi_s \leq \phi^*_s$ where ϕ^*_s is implicitly defined by $\phi^*_s = (H^2_c - H^2_n)/2[\pi^{\#}_s(x^c) - \pi^{\#}_s(x^n)]$.*

Proof. From the differentiation of eq. (15a) with respect to α, ϕ_m and β and using the above assumptions.

The intuition behind the first result is easy. An increase of α increases ε because the Southern firm is less keen to defect. This gives the multinational the possibility to obtain a larger share of profits in the developing country market. Since R&D cooperation increases these profits, a larger α increases the return of R&D cooperation for the multinational firm. At the same time, an increase of α reduces the difference between $\pi^*_{s,c} - \pi^*_{s,n}$, thus reducing the incentive to cooperate in R&D for the developing country firm. This second effect is dominated by the first one.

The second result can be explained as follows. When ϕ_m is small, the amount of R&D is larger both in the cooperative and in the non-cooperative case. However, the increase of R&D, induced by the spillover change in the cooperative case, becomes larger, thus reducing costs and increasing profits. In other words, if ϕ_m is small, R&D becomes less costly and it is therefore more convenient to carry it out cooperatively, when knowledge is fully shared between the two firms. Notice that R&D cooperation is profitable only if $\phi_m \leq \phi^*_m$ and $\phi_s \leq \phi^*_s$, where ϕ^*_m and ϕ^*_s are defined above. This result implies that it is not convenient to cooperate in R&D if one of the partners is particularly inefficient in carrying out its R&D.

A change of β has several effects. First, a lower β increases the difference between R&D costs with and without cooperation. At the same time, though, when β decreases, the impact of R&D cooperation on production costs becomes larger, because β is less close to 1, the level of spillovers in the cooperative case. This increases the difference $\pi^{\#}_s(x^c) - \pi^{\#}_s(x^n)$[6]. The net change in benefits

[6] Notice that when β_s increases, the southern firm's duopoly profit increases. This reduces the threat to the southern firm which has a larger incentive to defect from the technology sharing agreement. Therefore ε must be lowered (see eq. (4)). However, this does not reduce the incentive to cooperate because the same effect occurs

with cooperation is positive for $\phi_S \leq \phi^*_S$ because we assumed that the effects on profits are larger than the effects on R&D costs. Notice that with respect to the standard literature on R&D cooperation (d'Aspremont-Jacquemin, 1988; Suzumura, 1992) our result states that R&D cooperation is more likely when β is low rather than high. This can be explained by the fact that spillovers are usually assumed to be the same in the cooperative and non-cooperative case, whereas in our framework, when firms cooperate, there is full transfer of knowledge and the spillover becomes equal to one. The consequent reduction of costs is the dominant effect which explains why the lower the spillover without cooperation, the more profitable is R&D cooperation.

A further remark is important. In order to assess the factors which explain the available empirical evidence on the emergence of cooperative R&D between multinational and developing country firms, it is not sufficient to understand when the multinational finds it profitable to cooperate on R&D once it chooses the agreement. It is also important to understand this latter choice, because in the model no R&D cooperation takes place if the two firms decide to compete in the developing country market. It is indeed possible that some of the factors which increase the multinational's incentive to cooperate (the difference $\pi^*_{m,c} - \pi^*_{m,n}$) reduce its incentive to choose the agreement.

Let us therefore move to the first stage of the game.

2.6. Subsidiaries versus arm-length agreements

The multinational chooses to implement an agreement with the developing country firm iff:

(16) $$\pi^*_{m,i} \geq \pi^\circ_m(\beta_m,\beta_S) \qquad i=c,n$$

Under what conditions is this inequality more likely to be satisfied? Is it when the two firms cooperate in R&D? First, let us analyse which factors affect the difference $\pi^*_{m,c} - \pi^\circ_m(\beta_m,\beta_S)$. Let us write the profit when the multinational opts for the agreement as a function of β. Then, in the non-cooperative case:

(17a) $$\pi^*_{m,n}(\beta) - \pi^\circ_m(\beta_m,\beta_S) =$$

---

both in the cooperative and non cooperative case. By contrast, this effect may reduce the incentive to implement the technology sharing agreement (see below).

$$= \alpha[\pi^{\#}_s(x^n(\beta)) - (1/2)\phi_s(x^n_s(\beta))^2 - \pi^\circ_s(\beta_m,\beta_s)] - (1/2)\phi_m(x^n_m(\beta))^2 - \pi^\circ_m(\beta_m,\beta_s)$$

$$= \alpha M(x^n(\beta)) - (1-\alpha)\pi^\circ_m(\beta_m,\beta_s) - (\alpha H_n(\beta)^2/2)[(\phi_s + \alpha\phi_m\beta^2)/\phi_s\phi_m]$$

where $M(x^i)$, $i=c,n$, is the monopoly surplus, i.e. the difference between monopoly profits and duopoly profits in the developing country market: $M(x^i) = \pi^{\#}_s(x^i) - [\pi^\circ_m(\beta_m,\beta_s) + \pi^\circ_s(\beta_m,\beta_s)]$.

Notice that:

- $\alpha M(x^i(\beta))$, $i=c,n$, is the share of the monopoly surplus which goes to the multinational. It increases with β;
- $(1-\alpha)\pi^\circ_m(\beta_m,\beta_s)$ is the share of the multinational's duopoly profit (the profit that the multinational can guarantee itself by producing in the developing country) which goes to the southern firm;
- $(\alpha H_n(\beta)^2/2)[(\phi_s + \alpha\phi_m\beta^2)/\phi_s\phi_m]$ are the multinational's R&D costs plus the share of the developing country firm's R&D costs implicitly covered by the multinational through the share $1-\varepsilon$ of profits which are left to the southern firm.

Symmetrically, in the case in which firms cooperate in R&D:

(17b) $$\pi^*_{m,c}(1) - \pi^\circ_m(\beta_m,\beta_s) =$$

$$= \alpha[\pi^{\#}_s(x^c(1)) - (1/2)\phi_s(x^c_s(1))^2 - \pi^\circ_s(\beta_m,\beta_s)] - (1/2)\phi_m(x^c_m(1))^2 - \pi^\circ_m(\beta_m,\beta_s)$$

$$= \alpha M(x^c(1)) - (1-\alpha)\pi^\circ_m(\beta_m,\beta_s) - (H_c(1)^2/2)[(\phi_s + \alpha\phi_m)/\phi_s\phi_m]$$

From these equalities we can conclude that:

Proposition 3: *The arm-length agreement is the multinational's optimal strategy when the developing country firm's discount rate is low (α is high), when its duopoly profit is low (β_m is low, β_s is large), and when the monopoly surplus is large (β is large in the non-cooperative case).*

Proof: When α is large the share of the monopoly surplus which goes to the multinational increases, whereas the share of *m*'s duopoly profit which implicitly goes to the southern firm decreases. At the same time, the R&D cost increases because the amount of R&D increases with α and because the share of costs paid by the multinational increases. However, this is a second order effect, dominated by the two previous ones. When β_m is low and β_s is large, *m*' duopoly profits are low ($\partial\pi°_i/\partial\beta_i > 0$, $\partial\pi°_i/\partial\beta_j < 0$, $i,j=m,s$, $i\neq j$), thus reducing the loss $(1-\alpha)\pi°_m(\beta_m,\beta_s)$. Finally, when $M(x^i)$, $i=c,n$, increases, both $\pi^*_{m,c}(1) - \pi°_m(\beta_m,\beta_s)$ and $\pi^*_{m,n}(\beta) - \pi°_m(\beta_m,\beta_s)$ increase. This latter difference increases with β because $\pi^*_{m,n}(\beta)$ is an increasing function of β.

A potential problem with proposition 3 is that β and β_s are likely to be positively correlated. Thus, an increase in β increases the monopoly profit, but the contemporary increase in β_s will raise the Southern firm's duopoly profits. In turn, an increase in $\pi°_s(\beta_m,\beta_s)$ reduces ε, i.e. the share of monopoly profits to the multinational. Therefore, even if the net effect of increasing spillovers is to make the agreement relatively more profitable, there is a trade off, unless the correlation between β and β_s is sufficiently low.

The choice of cooperating in R&D breaks this correlation, as β is always 1 In other words, for any level of spillovers, cooperation maximises the diffusion of knowledge and, thus, monopoly profits. This leads us to the final issue to be analysed. Is the profitability of the arm length agreement with respect to the subsidiary consistent with cooperation in R&D? When the multinational opts for the agreement, does it also choose to cooperate in R&D? The answer is provided by the following proposition:

Proposition 4: *Whenever R&D cooperation is profitable, it is also profitable to opt for an arm length agreement rather than for the subsidiary. This always holds if the asymmetry in R&D efficiency is large.*

Proof. The difference between $\pi^*_{m,c}(1) - \pi°_m(\beta_m,\beta_s)$ and $\pi^*_{m,n}(\beta) - \pi°_m(\beta_m,\beta_s)$ is positive iff:

$$\alpha[M(x^c(1)) - M(x^n(\beta))] - [H_c(1)^2(\phi_s + \alpha\phi_m) - \alpha H_n(\beta)^2(\phi_s + \alpha\phi_m\beta^2)]/2\phi_s\phi_m > 0$$

whereas R&D cooperation is profitable for the multinational iff:

$$\alpha[M(x^c(1)) - M(x^n(\beta))] - [H^2_c(1-\alpha^2\beta^2)+(H^2_c-H^2_n)(\phi_m/\phi_s+\alpha\beta^2)]/2\phi_m > 0$$

The second inequality implies the first one if:

$$\phi_m/\phi_s < \alpha(1-\beta^2)/(1-\alpha^2\beta^2)$$

i.e. if the R&D efficiency of the multinational is sufficiently larger than the one of the developing country firm. Note that this is a sufficient and not a necessary condition. The implication is that R&D agreement will emerge *also if* the asymmetry in R&D efficiency between the two partners is large. Also recall that R&D cooperation does not affect the share with which the monopoly surplus is divided between the two firms (Proposition 1).

Therefore, from Proposition 4, the profitability of R&D cooperation implies the profitability of the arm-length agreement with respect to the subsidiary, which implies that the multinational is likely to opt for the agreement whenever R&D cooperation is profitable. Note, however, that the opposite statement is not true: as discussed in Proposition 3, there may be values of ϕ and β for which R&D cooperation is less profitable than a non cooperative arm length agreement.

2.6. Main intuitions and results of relevance for the empirical analysis

The major intuitions from the theoretical model can be summarised into the following points, some of which provide hypothesis to be tested in the empirical analysis below.

First, spillovers are costly for the R&D intensive multinational. Indeed, if the multinational produces directly in the developing country its duopoly profits will be lower; if it implements an agreement with a local firm, its share of the monopoly profits will also be lower. However, the net effect of increasing spillovers is to raise the relative profitability of the agreement, with respect to the subsidiary (Proposition 3).

Second, an arm length agreement is a mean to internalise knowledge spillovers. Under the agreement, the multinational will touch a share of monopoly profits. If there is no R&D cooperation, monopoly profits will be larger, the larger the spillovers. In this framework, R&D cooperation is not a tool to internalise spillovers: the agreement per se is the 'internalising device'. R&D cooperation, though, increases overall monopoly profits, as it transform the spillover into deliberate (and larger) transfer of knowledge from the multinational to the Southern firm. Therefore, it makes the multinational more likely to choose the arm length agreement than the subsidiary (Proposition 3).

Does it also stabilise the agreement ? i.e. does it make the Southern firm less likely to defect at the end of the first period?. This is not the case, unless R&D cooperation generates long term synergies between the partners and changes the inter-temporal preferences of the Southern firm (Proposition 1).

Third, inter-temporal preferences of the Southern firm, the efficiency in R&D of the two firms, and the extent of spillovers, all affect the choice of cooperating in R&D. Cooperation is more likely if the Southern firm cares much about the future benefits of the agreement (because it will be less likely to defect), if the multinational's R&D efficiency is high (because the increased R&D effort is cost efficient), if the Southern firm's R&D efficiency is not exceedingly low (otherwise there is free riding on the multinational's R&D effort) and if spillovers are relatively small (because if spillovers are large, there is a large transfer of knowledge even without cooperation and the net benefits of cooperation are small) (Proposition 2). The last result underlines the ambiguous role of spillovers. On the one hand they must be large enough to make the arm-length agreement the optimal choice (from Proposition 3). On the other hand, the larger they are, the smaller the relative profitability of R&D cooperation (Proposition 2).

Fourth, whenever R&D cooperation is profitable, the multinational opts for the arm-length agreement (Proposition 4). In contrast, the reverse statement is not necessarily true, i.e. the profitability of the agreement does not imply the profitability of R&D cooperation (otherwise arm length agreements without R&D cooperation would not exist). Proposition 4 always holds when the multinational's R&D efficiency is large relatively to the Southern firm. This is the standard case in the North-South context. Therefore, R&D cooperation in arm length agreements is an optimal outcome, also when there is asymmetry in R&D efficiency between the partners. Yet, we know from the previous point, that inefficiencies must not be too large: if the Southern firm has exceedingly small skill endowments and, consequently, exceedingly high R&D costs, cooperation is no longer feasible (Proposition 2).

Fifth, asymmetries are consistent with R&D agreements, because we assume unilateral spillovers (from North to South) within the agreement. In fact, most of the burden of the additional R&D investment under cooperation is on the shoulders of the multinational. Furthermore, duopoly profits of the Southern firm (its future profits under defection) are lower and, in turn, the multinational's share of monopoly profits is larger. This result would no longer hold if we were to assume bilateral spillovers, when the R&D activity carried out within the agreement affects the

Table 1

	JOINT EXCHANGE OF TECHNOLOGY (equal footing)					HIERARCHICAL TRANSFER							ROW TOT.
	Equity		*Joint R&D or Sharing - no Equity*		*tot. joint excha*	*Costumer - Supplier (joint R&D or production)*		*One-way technology transfer*		*Equity*		*tot hier. trans*	
R&D	Joint Venture	36	Joint Research Pact	3		Research Contract	10	JDA +Licensing	4	Joint Venture + Licensing	10		
			Joint Development Agreement (JDA)	23									
			Bidding Consortium	10									
			JDA +Technology Sharing	5									
COLUMN TOT		36		41	77		10		4		10	*24*	*101*
SHARING /TRANSFER	Joint Venture	85	Technology Sharing	9		Co-Makership Contract	2	Second Source Agreement	2	Joint Venture + Licensing	72		
	Cross Holding	1	Mutual Second Source Agreement	0		Customer Supplier Partnership	70	Licensing	137	Minority Holding	90		
								Second Source Agreement +Licensing	8				
								Technology Sharing +Licensing	54				
								Customer Supplier Partnership +Lic.	1				
COLUMN TOT		86		9	*95*		72		202		162	*436*	*531*
SAMPLE		122		50	172		82		206		172	460	632

multinational's overall profits elsewhere. This case is not studied in this paper, but we would expect that R&D cooperation is more likely to arise if asymmetries are small.

3. The empirical analysis

The empirical analysis is based on a sample of arm-length agreements and joint ventures of both R&D and non R&D types. R&D agreements are always of a cooperative nature. The sample includes 632 agreements in 29 developing countries established before 1989. A detailed description of the data base can be found in the appendix.

Table 1 shows the distribution of the observations according to the type of agreement. Each type of agreement has special characteristics, which may affect the incentive structure. At this level of analysis it is possible to group them according to three major criteria. The *first* one is whether agreements imply R&D activities, or whether they don't. The *second* criteria is whether the relationship between the partners is hierarchical, i.e. whether it is possible to clearly identify a customer and a supplier. The *third* criteria is whether the agreement is characterised by equity sharing. In this group we have joint ventures and minority holdings.

We are able to test under which conditions firms that form an arm-length agreement also decide to cooperate in R&D. Unfortunately the data base does not allow us to test also the decision of establishing a subsidiary vs. an arm-length agreement, as it does not include subsidiaries. Consequently, we can only assess some of the results and some of the key assumptions of our theory. Table 1 lists the assumptions and results of the theory tested in the empirical analysis.

Table 2 Assumptions and results of the theory tested in the empirical model

Assumptions
Both partners contribute to the R&D effort
Equity type sharing rule
R&D to reduce production costs, not to improve product quality
Results
R&D efforts not excessively asymmetric
Technological asymmetries between firms small
North-South spillovers low

We use a dichotomous choice model, in that the dependent variable takes value 1 if agreement i is of the R&D type and 0 otherwise (R&D). We will use the *probit* technique to test the probability that the dependent variable is explained by the independent ones. The model can be spelled out as follows:

$$P(R\&D_i=1)= \alpha + \beta_i X_i + \nu_{in} Y_{in} + \gamma_{ij} Z_{ij} + \varepsilon_i \qquad (18)$$

where α is the constant, X_i is a vector of characteristics of the agreement i, Y_{in} is a vector of characteristics of the industry n where the product to which agreement i refers are classified, Z_{ij} is a vector of characteristics of country j where agreement i is located and ε_i is the error term. Unfortunately, the data base does not provide information on firm characteristics.

Table 3 lists all the variables used in the probit. The first group of variables represent *characteristics of the agreement*, (X_i) and in particular whether the relationship between the partners is hierarchical (HIERARCH) and whether the agreement is equity or non equity (EQUITY). In our theoretical model we have assumed that both partners contribute to R&D (it is not a hierarchical relationship) and we have shown that R&D cooperation is more likely if contributions are not excessively asymmetric. We therefore expect R&D cooperation to emerge when the agreement can be classified as non hierarchical. Equity defines a sharing rule and it is likely to be chosen when contracts are very complex and contingencies difficult to foresee. Uncertainty is typical of a long term R&D relationship. Yet, the theoretical model defines a sharing rule that fits well with both equity and non equity types of contracts. Thus it does not rule out any option.

Then, we test whether R&D is more likely to be related to vertical rather than horizontal investments. We assume that investments are horizontal if the agreement concerns the production and the development of products for the final market and vertical if it concerns the development of a factor of production or a production process (HOVER). Again, this variable tests one of the hypothesis of our model, that R&D is carried out to reduce production costs and not to develop new products.

Industry specific variables (Y_{in}) measure R&D intensity in the industry. R&D intensive industries are assumed to be knowledge intensive. The impact of knowledge intensity on spillovers is

Table 3
Variables used in the Probit Analisys

Variable	*Source*	*Description*
R&D (Dependent Variable)		Binary variable that assumes value 1 if the agreement is aimed at R&D activities, and 0 otherwise
A) Charachteristics of the agreement (XI)		
hierarch	CATI	Binary variable that assumes value 1 if the contractual relationship among the partners in the agreement is one of equal footing , and 0 if there is an unilateral transfer of inputs
equity	CATI	Binary variable that assumes value 1 if the firms involved in the agreement join in a equity institution (joint venture, research corporation, cross and minority holding) and 0 otherwise
hover		Binary variable that assumes value 1 if the agreement is aimed at developing products for the final market and 0 otherwise
regio	CATI	Binary variable that assumes value 1 if the agreement is set forth by at least two firms based in the same region of the world , and 0 otherwise
subenv	CATI	Subject Environment. Discrete variable that assumes value 1 if the agreement relates to one product or one piece of technology, 2 if it relates to a few , 3 if it relates to a very broad range of products or technologies
opcon	Merit	Operational Contest. Discrete variable that assumes value 1 if the operational contest of the agreement is national, 2 if it relates to a few states, 3 to a continent, 4 if it is worldwide
B) Firms' Dynamics (Vik)		
moreagre	CATI	Binary variable that assumes value 1 if at least one of the firms involved in the agreement is engaged in other agreements , and 0 otherwise
mormore	CATI	Binary variable that assumes value 1 if the same firms involved in the agreement are engaged in more than one agreement , and 0 otherwise
C) Charachteristics of the industry (Yin)		
pavitt	CATI	Pavitt's index of industry 's technological charachteristics: 1= traditional; 2=specialised supplier; 3 = scale intensive; 4 = science intensive
redint	OCSE	Index of R&D intensity in the sector
D) Characteristics of the country (Zij)		
D1) Technological capabilities of the country		
gdpop	Barro-Lee	Real GDP per capita (1985 international prices), 1985
setech	United Nations	Number of scientist, engineers and technicians involved in R&D activities on total population, 1985
redgdp	United Nations	Total expenses in R&D on GDP
patent	United Nations	Patent applications on total population 1988-1990
indes	United Nations	Industrial designs applications on total population 1988-1990
trade	United Nations	Trade marks applications on total population 1988-1990
manu	World Bank	Share of Manufacturing on GDP, 1985
high	Barro-Lee	Total gross enrollment ratio for higher education.1985
persec		Percentage of sectors with agreements involving R&D activities on the number of sectors in which agreements take place in the country.
wages	I.L.O.	Wages in Manufacturing per hour, US dollars, 1985

ambiguous. On the one hand a larger share of the firm's intangible assets have ill defined property rights and is easily dispersed. On the other hand, learning could be more complex. We know, from the model, that the larger the spillovers, the lower the profitability of R&D cooperation. Hence the sign of the variable measuring R&D intensity of the industry, if significant, will depend on which of the two effects mentioned above (lack of property rights or complexity) prevails.

A variable which measures the average sector share of R&D expenditure on sales (REDINT), is a very noisy index of the public good nature of the firms' capital, as we cannot exclude that R&D industries could also be extremely capital intensive. Pavitt, 1984 provides a useful classification of industries into four groups: traditional, specialised suppliers, scale intensive and science based. The science based group isolates industries where knowledge capital is dominating (PAVITT).

We then move to *country specific* variables (Z_{ij}). These include indicators that proxy the technological capabilities or, more generally, the level of development, of the country. We know, from the model, that R&D agreements are less likely to emerge when technological asymmetries between firms are large. Unfortunately, our data base is extremely poor in information about the firms undersigning the agreements. It is therefore impossible to devise any indicator about technological capabilities at a firm level. Thus, we must confine ourselves to the use of country level variables.

The results of the probit are reported in table 4. We just show the most significant outcomes. Country data were not available for all the countries considered. Some of the initial observations had therefore to be dropped. Equation 1 includes the largest sample for which we were able to draw satisfactory results. The characteristics of the agreement and the nature of the relationship between the partners are very significant. Indeed, R&D contracts are more likely to emerge when the relationship between the partners is non-hierarchical (HIERARCH) and when it is characterised by equity sharing (EQUITY). The *non-hierarchical nature of R&D contracts* supports the basic co-operative structure assumed in our theoretical model, where both firms contribute to the R&D effort. At the same time, it shows that local firms must be able to actively interact with the foreign firm in developing the innovation. The *positive sign of the equity variable* confirms that contingencies related to R&D are often too many and complex to be regulated by straightforward arm-length contracts. Hence, first or second best non equity arm length R&D contracts cannot always be implemented, and thus equity sharing is an effective sharing rule. This supports the sharing rule assumed in the theory.

The HOVER variable is also very significant, and with a negative sign. As it takes value 0 for non-market oriented activities, we may infer that, consistently with our assumptions, *R&D contracts are more likely to be implemented in connection with vertical investments*, i.e. when R&D aims at reducing production costs.

The positive and significant coefficient of the Pavitt variable shows that *R&D contracts are likely to emerge in science based industries*, i.e. in industries where knowledge capital is a dominating firm's asset. The PAVITT variable performed better than REDINT (not shown in the table), which is unable to discriminate industries with both large tangible and intangible assets from industries which have only intangible assets like R&D and knowledge. Our sample only includes agreements and not subsidiaries of multinationals; therefore, it is probably biased towards activities with large spillovers (the theoretical model predicts that arm length agreements emerge when spillovers are large). The model also predicts that if spillovers are too large R&D cooperation is not viable. Thus, if our results holds, the positive sign of the Pavitt variable implies that, for ranges of activities with relatively large spillovers, spillovers are likely to be lower in knowledge intensive industries. Therefore, the effect of learning difficulties seems to dominate the effect of ill-defined property rights on intangible assets.

Two other significant variables measure the level of diffusion of R&D activity in the host country. REDGNP is the share of R&D expenditure on GNP in the country. PERSEC measures, for each country, the share of sectors in the sample where there is at least one R&D agreement. In other words, it measures whether R&D agreements are concentrated in just one or few specialised sectors, or whether they are spread in the manufacturing sector in general. R&D agreements are therefore more likely to emerge the larger and the more widely diffused R&D activity in the host country. As far as country characteristics can proxy firms characteristics, this result confirms the prediction of the theoretical model: R&D agreements do not happen when asymmetries in R&D efficiency and R&D investments are too large.

The negative coefficient of WAGE is not easy to explain. As we are considering a sample of developing countries, and as far as wages do reflect the education level of the labour force, we would expect R&D to be located in countries with higher average wages (i.e. WAGE to enter with a positive

Table 4

Probit Estimates

	1	Large Sample				2	NICs Sample			
Dependent Variable: R&D		Coef.	Std. Err.	z	P>|z|		Coef.	Std. Err.	z	P>|z|
cons		-3,152158	0,523168	-6,025	0		-2,935445	0,673914	-4,356	0
equity		0,326194	0,196111	1,663	0,096		0,72641	0,290849	2,498	0,013
hierarch		1,636574	0,186282	8,785	0		1,443977	0,254291	5,678	0
hover		-0,945347	0,214642	-4,404	0		-1,179904	0,272208	-4,335	0
pavitt		0,372248	0,110158	3,379	0,001		0,450809	0,170223	2,648	0,008
persec		1,58837	0,535264	2,967	0,003		-	-	-	-
redgdp		32,77965	11,22378	2,921	0,003		29,42076	12,21903	2,408	0,016
subenv		0,170206	0,150653	1,13	0,259		-	-	-	-
wage		-0,50919	0,15283	-3,332	0,001		-	-	-	-
Log Likelihood =	-137,2343					-70,83352				
Pseudo R2	0,3825					0,4244				
Number of obs =	514					269				

N. B.

Countries in probit 1:

Argentina	Hong Kong	Jamaica	Philippines	Thailand
Brazil	Hungary	S. Korea	Poland	Turkey
China	India	Mexico	Singapore	Venezuela
Egypt	Israel	Pakistan	S. Africa	Yugoslavia

Countries in probit 2:

Hong Kong	S. Korea
Israel	Taiwan
Singapore	

sign). Probably, this result is linked to the concentration of R&D contracts in vertical investments (where a cheap labour cost is a key determinant).

The theoretical results and probit 1 in table 4 support the hypothesis that R&D agreements are more likely to emerge when asymmetries are low. These type of agreements would therefore be more frequent in Newly Industrialising Countries (NICs) than in other country, where they are likely to be subscribed only in exceptional cases. Indeed, probit 2, which includes only observations for five NICs, Hong Kong, Israel, South Korea, Taiwan and Singapore performs better than probit 1, but the role played by each variable is roughly unchanged.

4 Conclusions

International dispersion of R&D activity also concerns developing countries. Although most of it is concentrated in the NICs, our data base shows important and considerable exceptions. Indeed, both our theory and empirical evidence show that R&D can be carried out via arm-length agreements, even between partners with asymmetric endowments of knowledge. Thus, developing countries firms are actively involved in international R&D, which is not the sole domain of subsidiaries of multinational.

This result takes us beyond the standard framework applied to the relationship between knowledge and technology transfer. Multinationals are generally assumed to have an effective internalisation option, i.e. if they want to avoid technological spillovers they set up subsidiaries instead of (less costly) arm-length agreements. Hence, to prevent knowledge spillovers, multinationals carry out R&D in developing countries with subsidiaries.

In fact, subsidiaries are not water tight. Spillovers may occur towards host country competitors, or the subsidiaries employees could set up a new company. The only effective way to internalise spillovers is through agreements which buy in the loyalty of the learning party. Our theory shows that R&D cooperation is a tool to make these agreements more profitable and more stable, as far as it strengthens the bindings and the relationship of trust between the partners.

Spillovers have an ambiguous effect on R&D agreements. They must be sufficiently large to induce firms to internalise them through an agreement. But if they are too large the partners have no interest in cooperating in R&D, once the agreement is formed. Indeed, when spillovers are very large, they generate a transfer of knowledge which is almost as large as under R&D cooperation.

The empirical analysis, which tests the decision of cooperating in R&D once the agreement is formed (the sample does not include subsidiaries), supports some of the key assumptions and results of the theory. R&D agreements are mostly non-hierarchical: firms cooperate on an equal footing base, in that each partner contributes to the R&D effort. Such contribution and the technological capabilities of the partners may differ, but, as confirmed by the evidence, asymmetries must not be too large. Most R&D agreements are based in Newly Industrialising Countries, which have relatively advanced industrial bases and capabilities.

We also find significant evidence that most agreements take place in research intensive industries, where knowledge capital is dominating. In these industries spillovers are likely to be low (confirming the predictions of the theory), as far as the effects of learning difficulties dominate on the effects of ill-defined property rights on knowledge capital.

Appendix: background to the empirical analysis

The Merit/Cati Data Base

Our sample has been extracted from Merit/Cati data bank on technological agreements. This data bank concerns nearly 10.000 agreements among firms located in more than 60 countries established before 1989. The main source of the data is the press, mostly newspapers and business journals. Information about the existence of agreements also has been gathered from companies' annual reports and business yearbooks[7].

The data bank considers technological co-operative agreements. A technology transfer or a common innovative activity must be the aim of at least a relevant part of the agreement. The definition of co-operative agreement utilised in the data bank is "common interests between independent (industrial) partners which are not connected through (majority) ownership" (Duysters and Hagedoorn, 1994). This broad definition includes a wide range of contractual forms[8], from customer-supplier relationships and licensing (in which the common interest stems only from the royalties the licensing firm gains from the licensee's profits) to more closer form of co-operation among totally independent partners like bidding consortia, joint development agreements, joint research pacts, or agreements involving equity sharing, like joint ventures or minority holding.

Constructions of the variables from the data base

We generated our dependent variable and a few explanatory variables by aggregating the agreements according to the following criteria. In order to divide the agreements between *R&D* and Non-R&D we had to move in two steps. Some of the agreements are obviously of an R&D type; these include, joint research pacts, joint development agreements and R&D contracts. In contrast, bidding consortia and most of all, joint ventures are in a grey zone. To classify the agreements we looked at the underlying motives, among which we could easily identify those related to R&D activities.

For the variable *Hierarch*, we once more relied on the definitions of the contractual forms. We derived a partition of the agreements into a group of equal footing relationships, in which all the parties were subject to symmetrical mutual contributions, and a group of unilateral transfers in which a hierarchical relationship between customers and suppliers was recognisable. For the variable *Hover*, we referred to the variable "distance to the market" of the CATI data bank. We classified as horizontal all agreements which concern the final market and as vertical otherwise.

[7] The Financial Time Industrial Companies Yearbooks and Dun & Bradstreet's "Who Owns Whom"

[8] For a complete list of the contractual forms used in the CATI data bank, see Duysters and Hagedoorn, 1993, pp. 12-13.

References

Aghion, Phillippe and Jean Tirole, 1994, 'Opening the Black Box of Innovation.', *European Economic Review*, 38, pp. 701-710.

d' Aspremont, Claude, and Alexis Jaquemin, 1988, 'Co-operative and Noncooperative R&D in Duopoly with Spillovers.' *The American Economic Review*, 78, No. 5, pp. 1133-1137.

Barba Navaretti Giorgio and Andrea Bigano, 1996, 'R&D Inter-firm Agreements in Developing Countries: Where? Why? How?', Fondazione Eni Enrico Mattei, Note di Lavoro, forthcoming

Bhattacharya S., Jacob Glazer, and David E. M. Sappington, 1990, 'Sharing Productive Knowledge in Internally Financed R&D Contests.' *Journal of Industrial Economics*, 39, No. 2, pp. 187-208.

Bhattacharya S., Jacob Glazer, and David E. M. Sappington, 1992, 'Licensing and the Sharing of Knowledge in Research Joint Ventures.' *Journal of Economic Theory*, 56, pp. 43-69.

Blomstrom, M. and A. Kokko, 1996, 'Multinational Corporations and Spillovers', Fondazione Eni Enrico Mattei, Note di Lavoro, forthcoming

Cantwell, John, 1993, 'Multinational Corporations and Innovatory Activities: Towards a New Evolutionary Approach.' University of Reading, Department of Economics, Discussion Papers in International Investment and Business Studies, N.172 Series B vol V.

Carraro, C. and D. Siniscalco (1996), 'International Coordination of Environmental Policies and the Implementation of International Environmental Agreements', in L. Bovenberg and S. Cnossen, eds., *Public Economics and the Environment in an Imperfect World*, Kluwer Academic Publishers, Dordrecht.

Coe, D.T., E. Helpman, A. W. Hoffmaister, 1995, 'North South R&D Spillovers', Centre for Economic Policy Research (CEPR) Discussion Paper Series, N.1133

Contractor, F.J. and P.Lorange, 1988, *'Cooperative Strategies in International Business'*, Lexington Books

David, Paul, 1993, 'Knowledge , Property and the System Dynamics of technological Change', *Proceedings of the World Bank Annual Conference on Development Economics, 1992*, The World Bank, Washington

Donsimoni, M.P., N.S. Economides and H.M. Polemarchakis (1986), "Stable Cartels", *International Economic Review*, 27, 317-327.

Duysters, Geert and John Hagedorn, 'The Co-operative Agreements and Technology Indicators (CATI) Information System', Merit, Maastricht, mimeo.

Ethier, Wilfred J., 1986, 'The Multinational Firm.' *Quarterly Journal of Economics*, 101, No. 4, pp. 805-833.

Ethier, Wilfred J. and James R. Markusen, 1991, 'Multinational Firms, Technology Diffusion and Trade.' NBER Working Paper No. 3825

Freeman, Chris and John Hagedorn, 1994, 'Catching up or Falling Behind: Patterns in International Interfirm Technology Partnering', *World Development*, vol. 22, No. 5, 771-780.

Horstmann, Ignatius J. and James R. Markusen, 1987, 'Strategic Investments and the Development of Multinationals.' *International Economic Review*, 28, No. 1, pp. 109-121.

Kumar, Nagesh, 1995, 'Intellectual Property Protection, Foreign Direct Investments and Location of Overseas R&D Activities by Multinational Enterprises.' United Nation University, Institute for New Technologies, Maastricht, mimeo.

Markusen, James R., 1995 'The Boundaries of Multinational Enterprises and the Theory of International Trade', *Journal of Economic Perspective* Vol. 9, No. 2, pp. 169-190

Motta, M. (1993), "Cooperative R&D and Vertical Product Differentiation, in *International Journal of Industrial Organization*.

Pavitt, Keith, 1984, 'Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory', *Research Policy*, 13, 343-373.

Pietrobelli, Carlo, 1996, 'Emerging Forms of Technological Cooperation: the Case for Tehnology Partnership', Unctad, Division for Science and Technology,

Vonortas, N.S., 1991, *'Research Cooperation in R&D INtensive Industries'* Academic Publishing Group, Aldershot

Wang, Jian-Ye and Magnum Blomström, 1992 'Foreign Investment and Technology transfer: a simple Model', *European Economic Review* 36, pp. 137-155.

Wright, Donald J., 1993, 'International Technology Transfer with an Information Asymmetry and Endogenous Research and Development.' *Journal International Economics*, 35, pp. 47-67.

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS1638	Private Pension Funds in Hungary: Early Performance and Regulatory Issues	Dimitri Vittas	August 1996	P. Infante 37642
WPS1639	Income Insecurity and Underemployment in Indonesia's Informal Sector	Franck Wiebe	August 1996	J. Israel 85117
WPS1640	Labor Regulations and Industrial Relations in Indonesia	Alejandra Cox Edwards	August 1996	M. McIntosh-Alberts 33750
WPS1641	Poverty and Inequality During Structural Adjustment in Rural Tanzania	M. Luisa Ferreira	August 1996	H. Taddese 31086
WPS1642	Banking Reform in Transition Countries	Stijn Claessens	August 1996	R. Velasquez 39290
WPS1643	The Consequences of Doubling the Minimum Wage: The Case of Indonesia	Martin Rama	September 1996	S. Fallon 38009
WPS1644	Pricing Industrial Pollution in China: An Econometric Analysis of the Levy System	Hua Wang David Wheeler	September 1996	H. Wang 33255
WPS1645	How Prices and Macroeconomic Policies Affect Agricultural Supply and the Environment	Nlandu Mamingi	September 1996	A. Williams 37176
WPS1646	Budgetary Institutions and Expenditure Outcomes: Binding Governments to Fiscal Performance	Ed Campos Sanjay Pradhan	September 1996	C. Bernardo 31148
WPS1647	The Baltics-Banking Crises Observed	Alex Fleming Lily Chu Marie-Renée Bakker	September 1996	S. Coffey 32635
WPS1648	The Lender of Last Resort Function Under a Currency Board: The Case of Argentina	Gerard Caprio, Jr. Michael Dooley Danny Leipziger Carl Walsh	September 1996	B. Moore 38526
WPS1649	Economic Regulation of Water Companies	Michael Klein	September 1996	S. Vivas 82809
WPS1650	Bank-Led Restructuring in Poland: An Empirical Look at the Bank Conciliation Process	Cheryl W. Gray Arnold Holle	September 1996	B. Moore 38526

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS1651	Bank-Led Restructuring in Poland: Bankruptcy and Its Alternatives	Cheryl W. Gray Arnold Holle	September 1996	B. Moore 38526
WPS1652	Intra-Industry Trade, Foreign Direct Investment, and the Reorientation of Eastern European Exports	Bernard Hoekman Simeon Djankov	September 1996	F. Hatab 35853
WPS1653	Grants and Debt Forgiveness in Africa: A Descriptive Analysis	Leonardo Hernández		
WPS1654	Indonesia's Palm Oil Subsector	Donald F. Larson	September 1996	P. Kokila 33716
WPS1655	Uncertainty and the Price for Crude Oil Reserves	Timothy J. Considine Donald F. Larson	September 1996	P. Kokila 33716
WPS1656	The Investment Decision: A Re-Examination of Competing Theories Using Panel Data	Cherian Samuel	September 1996	C. Samuel 30802
WPS1657	Is There an Optimal Structure for Decentralized Provision of Roads?	Frannie Humplick Azadeh Moini-Araghi	September 1996	J. Williams 82557
WPS1658	Decentralizing Structures for Providing Roads: A Cross-Country Comparison	Frannie Humplick Azadeh Moini-Araghi	September 1996	J. Williams 82557
WPS1659	Unemployment Insurance in Algeria: Implications for a Labor Market in Transition	Elizabeth Ruppert	September 1996	H. Osselyn 36039
WPS1660	Mind your P's and Q's: The Cost of Public Investment is *Not* the Value of Public Capital	Lant Pritchett	October 1996	S. Fallon 38009
WPS1661	Determinants of Public Expenditure on Infrastructure: Transportation and Communication	Susan Randolph Zeljko Bogetic Dennis Heffley		
WPS1662	From Learning to Partnership: Multinational Research and Development Cooperation in Developing Countries	Giorgio Barba Navaretti Carlo Carraro	October 1996	M. Patena 39515