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Ngo Van LONG* Antoine SOUBEYRAN†
Raphael SOUBEYRAN‡

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Abstract

This paper studies the properties of joint-venture relationship between a technologically advanced multinational firm and a local firm operating in a developing economy where the ability to enforce contracts is weak. We formulate a dynamic model of principal-agent relationship in which at any point of time the local firm can quit without legal penalties. An early breakup may be prevented if the multinational designs a suitable scheme in which both the pace and aggregate amount of technology transfer deviate from the first-best, and a suitable flow of side payments to encourage the local firm to stay longer.

*McGill University, 855 Sherbrooke Street West, Montreal, Quebec H3A 2T7.
†GREQAM, Université de la Méditerranée, Château Lafarge, route des Milles, 13290 Les Milles, France.
‡INRA-MOISA & IDEP, 2 Place Viala, 34060, Montpellier, France. Email: soubeyra@supagro.inra.fr

1 Introduction

Technology transfer from developed economies to less developed economies has been one of the key engines of growth of many emerging market economies. A quite common mode of technology transfer is the setting up of a joint venture between a multinational and a local firm. Governments of emerging market economies often encourage such joint ventures. In fact, the Chinese government does not allow foreign car manufacturers to have their own subsidiaries in China. It requires foreign car manufacturers to form joint ventures (JVs) with local firms so that the latter can benefit from technology transfer. In addition, foreign car manufacturers must obtain the Chinese government's permission to form JVs.

A salient feature of international joint ventures is that, in a large number of cases, breakup happens within a few years. The local partner of a joint venture may have strong incentives to break away, once it has accumulated sufficient technological knowledge. A multinational firm that offers a joint venture contract to a local firm must take into account the possibility of such opportunistic behavior. The breakup of joint ventures or similar collaborative agreements is a common feature of emerging market economies. Easterly (2001, p. 146) recounted that Daewoo Corporation of South Korea and Bangladesh's Desh Garment Ltd. signed a collaborative agreement in 1979, whereby Daewoo would train Desh workers, and Desh Ltd would pay Daewoo 8 percent of its revenue. Desh cancelled the agreement on June 30, 1981 after its workers and managers have received sufficient training. Its production soared from 43,000 shirts in 1980 to 2.3 million in 1987 (interestingly, of the 130 Desh workers trained by Daewoo, 115 eventually left Desh to set up their own firms). Hoekman, Maskus and Saggi (2005) review the principal channels of technology transfer, which are trade in goods, foreign direct investment, licensing, labor turnover and movement of people.

This paper studies the properties of joint-venture relationship between a technologically advanced multinational firm and a local firm operating in a developing economy where the ability to enforce contracts is practically non-existent. In our model the multinational firm always honors its promises (because it wants to maintain its reputation in other countries), and it cannot prevent the local firm from

breaking away after receiving its technology transfer. As a result, the multinational firm may have to rely on second-best technology transfer schemes that do not maximize joint surplus, but that are incentive compatible. This results in a total amount of technology transfer that is well below the first-best level.[1]

We formulate a dynamic model of principal-agent relationship in which at any point of time the agent (the local firm) can quit without legal penalties. An interesting feature of the model is that the agent's reservation value is changing over time, because the agent's knowledge capital increases with the accumulated amount of technology transfer. The agent's quitting value (i.e., how much it can earn as a stand-alone firm over the remaining time horizon) is a non-monotone function of time. Given a planned time path of technology transfer, during the early phase of the relationship, the local firm's quitting value is rising with time. However, near the end of the time horizon, when the transferred technological knowledge would become useless because a new product (developed elsewhere) renders the existing product completely obsolete, the local firm's quitting value is falling over time. Because of this non-monotonicity of quitting value, the local firm's optimal quitting time (in the absence of side transfer payments) occurs before the projected end of the first-best relationship. Such an early breakup may be prevented if the principal (the multinational) designs a suitable scheme in which both the pace and aggregate amount of technology transfer deviate from the first-best, and a suitable flow of side payments to encourage the local firm to stay longer.

We ask the following questions: (i) When first-best contracts are not implementable, is the speed of technology transfer reduced? (ii) Is the cumulative amount of technology transfer lower under the second-best scheme? (iii) Does the side payment increase over time? (iv) What is the optimal time to let the local

[1] This may be interpreted as the unwillingness to transfer the latest technology. In Glass and Saggi (1998)'s general equilibrium model, the quality of technology that FDI transfers depends on the size of the technology gap between the North and the South. Empirical work by Coughlin (1983) found that comparing countries that are not favorable to FDI that set up wholly owned subsidiaries with countries having less restrictive FDI policies, the first group of countries tend to receive process rather than product technology transfers, and the product technology transfers tend to concentrate on older products.

firm break away?

Other questions that can also be discussed using our model are: Does trade liberalization (e.g. lowering tariffs) has unfavorable impact on technology transfer? Does competition with other local firms has an impact on the technology transfer? Given that technology transfer in one industry can have beneficial spillovers in other industries, what could the government of the recipient country do to improve social welfare by changing the parameters of the second-best schemes? (Section 5 discusses some of these issues).

In modelling the endogenous pace and duration of technology transfer, our paper supports the hypothesis that the degree of intellectual property protection influences the extent of technology transfer (for a survey of empirical evidence, see Mansfield, 1994). In our model, the timing decisions and the pace of technology transfer play a crucial role. This distinguishes our paper from other papers which typically use a static framework to analyze technology transfer issues[2]. This is not to deny the usefulness of the static framework. Static models are often a convenient short-hand description of a dynamic process, or of a long run outcome of a dynamic process.

Our model is an enrichment of the two-period models of Ethier and Markusen (1996), Markusen (2001), and Roy Chowdhury and Roy Chowdhury (2001). While these three papers offer valuable insights on internalization considerations, our result on the non-monotonicity of quitting value cannot be obtained in such two-period models, where, by necessity, things can either go up or go down over time, not up and then down. This non-monotonicity has important bearing on the principal's optimal speed of technology transfer.

Ethier and Markusen (1996) presented a model involving a race among source-country firms to develop a new product that becomes outdated after two periods.[3] The winning firm has the exclusive right to produce the good in the source country (S), and can produce the good in the host country (H) either by setting up a wholly owned subsidiary, or by licensing to a local firm. If the licensing contract is for one

[2]See for example, Kabiraj and Marjit (2003), Mukherjee and Pennings (2006), in which technology transfer is via licensing, which does not use up real resources.

[3]With this assumption, the time horizon of a firm is effectively restricted to two periods.

period, in the following period the former licensee, having learned the technology, can set up its own operation to compete against the source-country firm (two-period licensing is ruled out because by assumption the local firm can breakaway in the second period without penalties). The model captures essential elements of a situation where source-country firms "continually compete to introduce new products" and face possible dissipation of their knowledge-based capital. The authors assume that in the host country there is complete absence of protection of intellectual property. Their model highlights the interplay of locational and internalization considerations. It provides a key to understand why there are more direct investment between similar economies. Their paper does not address the issue of *endogenous timing of breakaway by the local partner* of a joint venture, nor the issue of the multinational's *optimal speed of technology transfer that serves to counter the breakaway incentives.*

Markusen (2001) proposed a model of contract enforcement between a multinational firm and a local agent. He considered a two-period model where the agent learns the technology in the first period and can quit (with a penalty) and form a rival firm in the second period. The multinational can fire the agent after the first period and hire another agent in the second period. The main result is that if contract enforcement induces a shift from exporting to local production (within a multinational-local agent contract), both the multinational firm and the local agent are better off. Markusen's paper does not address the issue of the optimal speed of technology transfer.

Roy Chowdhury and Roy Chowdhury (2001) built a model of joint venture breakdown. They used a two-period setting, with a multinational firm and a local firm. They showed that for intermediate levels of demand, there is a joint venture formation between these firms in period 1, followed by a joint venture breakdown in period 2 (when the two firms become Cournot rivals). In their model, the incentive for forming a joint venture is that both firms can learn from each other (the local firm acquires the technology while the multinational learns about the local labor market). The model does not allow the multinational to control the speed of technology transfer.

In the papers mentioned above, by restricting to two-period models, the question of optimal timing of breakup cannot be studied in rich detail. Among papers that deal with optimal timing decisions of multinational firms is Buckley and Casson (1981). They analyzed the decision of a foreign firm to switch from the "exporting mode" to the FDI mode (in setting up a wholly owned subsidiary). That paper did not deal with the problem of opportunistic behavior that would arise if there were a local partner. Horstmann and Markusen (1996) explored the multiperiod agency contract between a multinational firm and a local agent (that sells the multinational's product) but in their model there was no technology transfer from the former to the latter. Their focus was to determine when a multinational would terminate its relationship with the local sales agent and establish its own sales operation. Rob and Vettas (2003) generated the time paths of exports and FDI, with emphasis on demand uncertainty and irreversibility. They did not consider the possibility of licensing or joint venture. Horstmann and Markusen (1987) explored a multinational firm's timing decision on investing (setting up a wholly owned subsidiary) in a host country in order to deter entry. Lin and Saggi (1999) explored a model of timing of entry by two multinationals into a host country market, under risk of imitation by local firms. There was no contractual issues in their model; the emphasis was instead on the leader-follower relationship. They showed that while an increase in imitation risk usually makes FDI less likely, there exist parameter values that produce the opposite result.

An early paper that discussed the resource cost of transferring technology know-how was Teece (1977). Teece disagreed with the "common belief that technology is nothing but a set of blueprints that is usable at nominal cost to all". He argued instead that "the cost of transfer, which can be defined to include both transmission and absorption costs, may be considerable when the technology is complex and the recipient firm does not have the capabilities to absorb the technology". His empirical research focused on measuring the costs of transmitting and absorbing all of the "relevant unembodied knowledge". These costs fall into four groups. First, there are pre-engineering technological exchanges, where the basic characteristics of the technology are described to the transferee. Second, there are costs

of transferring and absorption of the process or product design, which require "considerable consulting and advisory resources". Third, there are "R&D costs associated with solving unexpected problems and adapting or modifying technology". Fourth, there are training costs, which involve extra supervisory personnel. Teece found that empirically the resources required for international technology transfer are considerable and concluded that "it is quite inappropriate to regard existing technology as something that can be made available at zero social cost" (p. 259). Niosi et al. (1995) found that technology transfer costs are significant and mostly concentrated in training.

The remainder of our paper is structured as follows. Section 2 introduces the model, and characterizes the first-best pace of technology transfer when contracts are perfectly enforceable, so that a joint-venture breakup is not allowed. Section 3 shows that if breakup can happen without penalties, and the local firm faces a credit constraint, then the first best pace of technology transfer is not an equilibrium outcome, because the multinational would want to modify the pace of technology transfer in order to (partially) counter the incentives of breakaway. We find that the equilibrium outcome under credit constraint and imperfect property rights involves a slower pace of technology transfer, and also results in a lower cumulative technology transfer. Section 4 shows that without credit constraint or with perfect property rights the first best pace of technology transfer is the equilibrium outcome. Section 5 discusses some policy implications. The Appendix contains proofs.

2 The Basic Model

2.1 Assumptions and Notation

We consider a developing country in which a good can be produced using local inputs (such as labor and raw material) and technological knowledge which can be transferred from a foreign firm. Unlike most existing models which assume that the technology transfer can happen immediately, we take the view that there are absorption costs and training costs which rise at an increasing rate with the speed

of technology transfer, and which make an once-over technology transfer unprofitable. We therefore explicitly introduce time as a crucial element in our model. We take time to be a continuous variable, $t \in [0, T]$. Here T is an exogenously given terminal time of the game. It can be interpreted as the time beyond which the product ceases to be valuable (cf. the product cycle theory of Vernon).

Let $h(t)$ denote the rate of technology transfer at time t. The state of technological knowledge of the local firm at time t is denoted by $H(t)$ where

$$H(t) = \int_0^t h(\tau) d\tau \tag{1}$$

The (reduced-form) "gross profit" of the joint venture at time t is assumed to be a function of $H(t)$ alone. It is denoted by $\pi(H(t))$ where $\pi(.)$ is a continuous, concave and strictly increasing function, with $\pi = 0$ if $H = 0$. This gross profit does not include "absorption cost" which is denoted by $C(h(t))$. We assume that $C(h)$ is continuous, strictly convex and increasing in h, with $C(0) = 0$. This implies that for all $h > 0$, marginal absorption cost is greater than average absorption cost, $C' > C/h$. We also assume that there is an upper bound on h, denoted by $h_{\max} > 0$.

Let us make the following specific assumptions:

Assumption A1: (a) The difference between marginal absorption cost and average absorption cost, $C'(h) - C(h)/h$, is positive and increasing in h for all $h > 0$. (b) $T\pi'(0) > C'(0) \geq 0$.

Assumption A2: The upper bound $h_{\max}$ is sufficiently great, such that

$$C'(h_{\max}) - \frac{C(h_{\max})}{h_{\max}} > \frac{T\pi'(0)}{2} \tag{2}$$

Assumption A3: The elasticity of marginal contribution of technology to profit is less than or equal to unity:

$$1 + \frac{H\pi''(H)}{\pi'(H)} \geq 0 \tag{3}$$

Remark 1: Assumption A1(a) implies that

$$C''(h) - C'(h)h^{-1} + C(h)h^{-2} > 0 \tag{4}$$

Clearly, the function $C(h) = (1/\alpha)h^{\alpha}$ where $\alpha > 1$ satisfies A1(a). Assumption A1(b) means that the return (over the life-time of the joint venture) of a very small technology transfer is higher than its marginal cost. Assumption A3 implies that $t\pi'(ht)$ is increasing in t. We use this assumption to prove the optimal solution is unique (see Proposition 1 below) and to show that the equilibrium outcome under credit constraint and imperfect property rights results in a lower cumulative technology transfer (see section 3.4). Clearly, the function $\pi(H) = (K/\gamma)H^{\gamma}$ where $0 < \gamma \leq 1$ and $K > 0$ satisfies A3.

We assume that the foreign firm and the local firm form a joint venture. We first consider the ideal case where contracts can be enforced costlessly. In this case the joint venture chooses a time path of technology transfer and production that maximizes the joint surplus. In analyzing this ideal case, our focus is on efficiency. The surplus sharing rule under this first-best scenario is not important for our purposes.

After characterising the first-best (efficient) time path of technology transfer, we discuss whether this path can be achieved if the local firm can at any time break away from the joint venture and become a stand-alone entity that captures all the post-breakaway profit (we assume that after the breakaway, the joint venture vanishes, and the multinational firm leaves the host country). The answer will depend on what kind of contracts are feasible, in particular, on whether the local firm has access to a perfect credit market, and whether the multinational is entitled to compensation by the local firm after the breakaway (i.e. whether property rights are perfectly enforceable). In the absence of a perfect credit market and a perfect property rights regime, we show that the foreign firm must design a second-best contract. We show that the second-best contract involves a slower pace of technology transfer, and a lower level of cumulative technology transfer. We argue that this outcome could be detrimental to the host country.

2.2 The first-best solution

For simplicity, we assume that the discount rate is zero. The joint-surplus maximization problem is to choose a time path $h(t)$ over the time horizon T to maximize

$$V = \int_0^T [\pi(H(t)) - C(h(t))]\, dt \tag{5}$$

subject to $\dot{H}(t) = h(t)$, $H(0) = H_0 = 0$ and $0 \leq h \leq h_{\max}$.

Let us simplify the problem by restricting the set of admissible time paths of technology transfer, so that it consists of the following two-parameter family of piece-wise constant functions (the case where $h(t)$ is not constrained to be piece-wise constant is analysed in a companion paper):[4]

$$h(t) = \begin{cases} h & \text{if } t \in [0, t_S] \\ 0 & \text{if } t \in (t_S, T] \end{cases} \tag{6}$$

where t_S is the "technology-transfer-stopping time", beyond which there will be no further technology transfer, and h is a constant transfer rate, to be chosen. After the time t_S, the level of technological knowledge of the joint venture is a constant, denoted by H_S where

$$H_S \equiv h t_S \tag{7}$$

The optimization problem of the joint venture then reduces to that of choosing two numbers h and t_S to maximize

$$V(h, t_S) = \int_0^{t_S} [\pi(ht) - C(h)]\, dt + [T - t_S]\, \pi\,(h t_S) \tag{8}$$

subject to $0 \leq h \leq h_{\max}$ and $0 \leq t_S \leq T$.

Proposition 1: *The solution of the (first-best) optimization problem (8) of the*

[4] In the companion paper, the optimal path $h^*(t)$ looks similar. It is maximal during the first few periods, then gradually decreases, becoming zero strictly before the horizon T. The main difference appears in the determination of the optimal second best flow of side payment $w^C(.)$. Indeed, when $h(t)$ can vary from one period to the next, the multinational can induce the local firm to delay the breakaway by accelerating the technology transfer instead of increasing the flow of side payments.

joint venture exists, is unique, and has the following properties:
(i) The rate of technology transfer h^* during the time interval $[0, t_S^*]$ is strictly positive and strictly below the upper bound $h_{\max}$.
(ii) The stopping time t_S^* is strictly positive and is smaller than the time horizon T.
(iii) The marginal benefit (over the remaining time horizon) of the technological knowledge stock at the stopping time t_S^* is just equal to the average absorption cost:

$$(T - t_S^*)\pi'(h^* t_S^*) = \frac{C(h^*)}{h^*}. \tag{9}$$

(iv) At the optimal technology transfer rate h^*, the excess of the marginal absorption cost over the average absorption cost is just equal to average of the marginal contribution of technology to profit over the transfer phase:

$$C'(h^*) - \frac{C(h^*)}{h^*} = \frac{1}{t_S^*}\int_0^{t_S^*}\left[\frac{\partial}{\partial h}\pi(h^* t)\right] dt \tag{10}$$

Proof : See the Appendix.
Remark 2: Since $C(h) > 0$ for any $h > 0$ and $H(0) = 0$, the assumption that $\pi(H) = 0$ when $H = 0$ implies that, for any $h > 0$, there exists an initial time interval called the "loss-making phase" over which the joint venture's net cash flow, $\pi(ht) - C(h)$, is negative. This phase ends at time $t^+(h)$ which is defined, for any given $h > 0$, as follows:

$$t^+(h) \equiv \min\left\{t_S, \sup_t \{t \in [0, T] : \pi(ht) < C(h)\}\right\} \tag{11}$$

Example 1: Assume $\pi(H) = K \times (1/\gamma)H^\gamma$ where $K > 0$, $0 < \gamma \leq 1$ and $C(h) = (c/\alpha)h^\alpha$ where $\alpha > 1$ and $c > 0$. Then using equations (9) and (10) we get:

$$t_S^* = \left(\frac{(\alpha - 1)(\gamma + 1)}{1 + (\alpha - 1)(\gamma + 1)}\right) T, \qquad h^* = \left(\frac{\alpha K}{c(\alpha - 1)(\gamma + 1)}\right)^{\frac{1}{\alpha - \gamma}} (t_S^*)^{\frac{\gamma}{\alpha - \gamma}} \tag{12}$$

and

$$t^{+}(h^{*}) = \min\left\{t_{S}^{*}, \left(\frac{\gamma c}{\alpha K}\right)^{\frac{1}{\gamma}} (h^{*})^{\frac{\alpha-\gamma}{\gamma}}\right\}. \tag{13}$$

Thus the cumulative transfer is

$$h^{*}t_{S}^{*} = \left(\frac{\alpha K}{c(\alpha-1)(\gamma+1)}\right)^{\frac{1}{\alpha-\gamma}} \left(\frac{(\alpha-1)(\gamma+1)}{1+(\alpha-1)(\gamma+1)}T\right)^{\frac{\alpha}{\alpha-\gamma}} \tag{14}$$

In the rest of the paper, we will illustrate our results with the three following numerical examples:

	h^{*}	t_{S}^{*}	$t^{+}(h^{*})$
Example 1a $T=30, \gamma=1, \alpha=2, c=1, K=2$	40	20	10
Example 1b $T=30, \gamma=\frac{1}{2}, \alpha=2, c=1, K=2$	$\simeq 5.04$	18	2
Example 1c $T=30, \gamma=1, \alpha=\frac{5}{4}, c=1, \ K=0.1$	$\simeq 39$	10	10

2.3 Implementation of the first best when the local firm cannot break away

Denote by $V(h^{*}, t_{S}^{*})$ the net profit of the joint venture under the first-best solution. Let us assume that the local firm would form a joint venture with the foreign firm only if the payoff to the owner of the local firm is at least equal to its reservation level R_L. We consider only the case where $R_L < V(h^{*}, t_{S}^{*})$. Assume there are many potential local firms. Then the foreign firm will offer the local firm the payoff R_L, and keep to itself the difference $V(h^{*}, t_{S}^{*}) - R_L$.

Suppose it is possible to enforce a contract that specifies that the joint venture will not be dissolved before the end of the fixed time horizon T. Then the foreign firm will be able to implement the first best technology transfer scheme that we found above. In the following sections, we turn to the more interesting case where the local firm is not bound to any long-term contract.

3 Joint venture contracts when the local firm can break away

We now turn to the real world situation where the local firm can break away at any time, taking with it the technological knowledge that has been transferred, without having to compensate the multinational. For simplicity, we assume that after the breakaway, the multinational is unable to produce in the host country. The local firm can break away at any time $0 \leq t_B \leq T$ and become a stand-alone firm in the local market, benefiting from the cumulative amount of technology transfer up to that date, $H(t_B)$. In this section, we assume the following market failures:

Credit market failure (C1): The local firm cannot borrow any money, hence the multinational has to bear all the losses of the joint venture during the loss-making phase $[0, t^+(h)]$, where $t^+(h)$ is as defined by equation (11) (the multinational firm is not subject to any credit constraint). The multinational firm cannot ask the local firm to post a bond which the latter would have to forfeit if it breaks away (the local firm cannot raise money for such a bond).

Property rights failure (C2): The multinational cannot get any compensation payments from the local firm after the breakaway time t_B.

Without the credit market failure, the multinational firm would be able to ask the local firm to pay as soon as it receives any technology transfer. Without the property rights failure, the prospect of having to compensate the multinational would deter the local firm from breaking away. Let us make clear the meaning of (C1) and (C2) above by describing the payoff function of the multinational and that of the local firm.

We assume that the multinational firm can credibly commit to honor any contract it offers. This assumption seems reasonable, because multinational firms operate in many countries and over a long time horizon, so it has an interest in keeping a good reputation. Then we can without loss of generality suppose that the multinational offers a contract which specifies that it collects all the profits of the joint venture, and pays the local firm a flow of side payments $w(t)$ for all t

until the local firm breakaway.

After the breakaway, if C2 does not hold, the multinational can successfully ask for a flow of compensation payment $\phi(t)$ from the local firm, to be paid from t_B to T. In the rest of this paper we analyse different situations where the flows $w(.)$ and $\phi(.)$ are constrained.

The total payoffs of the multinational firm and of the local firm are, respectively,

$$V_M \equiv \int_0^{t_B} [\pi(H(t)) - C(h(t)) - w(t)]\, dt + \int_{t_B}^{T} \phi(t)\, dt, \tag{15}$$

and

$$V_L \equiv \int_0^{t_B} w(t)\, dt + \int_{t_B}^{T} [\pi(H(t)) - \phi(t)]\, dt. \tag{16}$$

The payoff implications of the market failures (C1) and (C2) are described below.

C1: The local firm cannot borrow: In this case, at all time t, the local firm's cumulative net cash flow up to time t, denoted by $N_L(t)$, must be non-negative. Thus

$$0 \leq N_L(t) \equiv \begin{cases} \int_0^t w(\tau)\, d\tau & \text{if } t \in [0, t_B] \\ \int_0^{t_B} w(\tau)\, d\tau + \int_{t_B}^t [\pi(H(\tau)) - \phi(\tau)]\, d\tau & \text{if } t \in (t_B, T] \end{cases} \tag{17}$$

C2: The multinational cannot obtain from the local firm any compensation payment after the breakaway time:

$$\phi(t) = 0 \text{ for } t \in (t_B, T] \tag{18}$$

The goals of this section are (a) to show that when both constraints (17) and (18) hold the first-best technology transfer scheme is in general not achievable, and (b) to characterize the second-best technology transfer scheme. In a later section, we will point out that if one of these two assumptions is completely removed, the

first-best can be recovered.

3.1 Technology transfer with two market imperfections

We now consider the case where the local firm can break away, there is no credit market, and the multinational cannot get any side payment after the breakaway.

Using the constraint that $\phi(t) = 0$ and the fact that $\pi(H(t)) \geq 0$, the borrowing constraint C1, condition (17), can be simplified to

$$0 \leq \int_0^t w(\tau)\, d\tau \text{ for all } t \in [0, t_B]. \tag{19}$$

For simplicity, from this point we assume that the reservation value R_L is 0. Then the participation constraint $V_L \geq R_L$ is satisfied when the borrowing constraint (19) holds.

Then, the program of the multinational can be written as

$$\max_{h, t_S, w(.)} V_M = \int_0^{t_B} [\pi(H(t)) - C(h(t)) - w(t)]\, dt \tag{20}$$

subject to $0 \leq t_S \leq T$, $0 \leq h \leq h_{\max}$, the incentive constraint

$$t_B = \arg\max_t \left[V_L = \int_0^t w(\tau)\, d\tau + (T - t)\pi(H(t)) \right] \tag{21}$$

and the credit constraint

$$0 \leq \int_0^t w(\tau)\, d\tau \text{ if } t \in [0, t_B]. \tag{22}$$

Here

$$H(t) = \int_0^t h(\tau) d\tau, \tag{23}$$

and

$$h(t) = \begin{cases} h & \text{if } t \in [0, \min(t_S, t_B)] \\ 0 & \text{if } t \in (\min(t_S, t_B), T] \end{cases} \tag{24}$$

3.2 The local firm's secure payoff

Let us consider what would happen if during the profit-making phase, the multinational firm takes 100% of the profit and does not make any side transfer to the local firm. Under this scenario, clearly the local firm has an incentive to break away at or before the time t_S (after t_S, it has nothing to lose by breaking away). The local firm wants to choose a breakaway time $t_B \in [0, t_S]$. Given that $w(.) = 0$ identically, the payoff to the local firm if it breaks away at time t_B is

$$V_L^0(h, t_B) = (T - t_B)\pi(H(t_B)) \tag{25}$$

where

$$H(t_B) = \begin{cases} ht_B & \text{if } t_B < t_S \\ ht_S & \text{if } t_B \geq t_S \end{cases} \tag{26}$$

Here the superscript 0 in V_L^0 indicates that the local firm's share of profit before the breakaway time is identically zero. Given (h, t_S), the local firm knows that if it breaks away at time t_S, it will get $(T - t_S)\pi(ht_S)$. If it breaks away at some earlier time $t_B < t_S$, it will get $(T - t_B)\pi(ht_B)$. The local firm must choose t_B in $[0, t_S]$, to maximize

$$R(h, t_B) \equiv (T - t_B)\pi(ht_B) \text{ where } t_B \in [0, t_S] \tag{27}$$

Lemma 1: *Given that $w(.) = 0$ identically (i.e. there is no side transfer from the multinational to the local firm),*

(i) If

$$(T - t_S)\pi'(ht_S)h - \pi(ht_S) \geq 0 \tag{28}$$

the local firm will break away at the planned transfer-stopping time t_S, and earns the payoff $(T - t_S)\pi(ht_S)$.

(ii) If

$$(T - t_S)\pi'(ht_S)h - \pi(ht_S) < 0 \tag{29}$$

the local firm will break away at a unique $\widehat{t}_B(h)$, strictly earlier than the planned

transfer-stopping time t_S, and earn the (secure) payoff

$$\underline{V}_L(h) \equiv (T - \widehat{t}_B(h))\pi(h\widehat{t}_B(h)). \tag{30}$$

(iii) In both cases, a small increase in h will increase the local firm's payoff by $\left[T - \widehat{t}_B(h)\right] \pi'(h\widehat{t}_B(h))\widehat{t}_B(h) > 0$ where, in the first case, $\widehat{t}_B(h) = t_S$, and in the second case, $\widehat{t}_B(h)$ satisfied the interior first order condition:

$$(T - \widehat{t}_B(h))\pi'(h\widehat{t}_B(h))h - \pi(h\widehat{t}_B(h)) = 0 \tag{31}$$

Proof: The function $R(h, t_B)$ is strictly concave over $(0, t_S)$, because

$$\frac{\partial^2 R(h, t_B)}{(\partial t_B)^2} = (T - t_B)\pi''(ht_B)h^2 - 2\pi'(ht_B)h < 0 \tag{32}$$

Consider the derivative of $R(h, t_B)$ with respect to t_B;

$$\frac{\partial R(h, t_B)}{\partial t_B} = (T - t_B)\pi'(ht_B)h - \pi(ht_B) \tag{33}$$

Thus if $(T - t_S)\pi'(ht_S)h - \pi(ht_S) \geq 0$ then, due to the strict concavity of $R(h, t_B)$ in t_B, we know $(T - t_B)\pi'(ht_B)h - \pi(ht_B) > 0$ for all $t_B < t_S$, and it follows that the local firm will choose $t_B = t_S$. If $(T - t_S)\pi'(ht_S)h - \pi(ht_S) < 0$ then $R(h, t_B)$ attains its maximum at some $t_B < t_S$. To prove (iii), note that in the case of $\widehat{t}_B = t_S$ (corner solution), if after a small increase in h, the corner solution $\widehat{t}_B = t_S$ remains optimal, then $\partial \underline{V}_L(h)/\partial h = \left[T - \widehat{t}_B(h)\right] \pi'(h\widehat{t}_B(h))\widehat{t}_B(h)$ where $\widehat{t}_B(h) = t_S$. In the case of an interior solution, $\widehat{t}_B(h) < t_S$, differentiation of (30) gives

$$\begin{aligned} \partial \underline{V}_L(h)/\partial h &= \left[T - \widehat{t}_B(h)\right] \pi'(h\widehat{t}_B(h))\widehat{t}_B(h) \\ &\quad + \left\{(T - \widehat{t}_B(h))\pi'(h\widehat{t}_B(h))h - \pi(h\widehat{t}_B(h))\right\} \frac{dt_B}{dh} \end{aligned} \tag{34}$$

But the term inside the curly brackets $\{...\}$ is zero. This concludes the proof.

Remark 3: Strictly speaking, the (secure) profit should be written as

$$\underline{V}_L(h, t_S) \equiv (T - \widehat{t}_B(h, t_S))\pi(h\widehat{t}_B(h, t_S))). \tag{35}$$

However, this formalism is quite unnecessary.

Example 2: Use the specification of example 1. Independently of the value of h, if $t_S > \frac{\gamma}{\gamma+1}T$,condition (29) is satisfied, and the local firm will break away at $\widehat{t}_B = \frac{\gamma}{\gamma+1}T < t_S$. If $t_S \leq \frac{\gamma}{\gamma+1}T$, condition (28) is satisfied, and the local firm will break away at $\widehat{t}_B = t_S$ (see Appendix 2).

Using the parameters of example 1a, the interior-breakaway condition (29) becomes $t_S > 15$**.** In Figure 1, the curve $V(h^*, t_S)$, where $h^* = 40$, shows that the multinational payoff under the first-best scenario is single-peaked in t_S, and its optimal t_S is $t_S^* = 20$. Now, given $h^* = 40$ and $t_S^* = 20$, under the imperfect property rights regime, the local firm can break away at time t_B and earns a payoff $R(h^*, t_B)$**.** We find that $R(h^*, t_B)$ is *non-monotone* in t_B: if the local firm (firm L) breaks away too early, it has too little knowledge capital to take away. If it breaks away too late, it has a lot of knowledge capital to take away, but too little remaining time before the end of the time horizon. The local firm will break away at $\widehat{t}_B\,(h^*) = 15$. This shows that the first-best scheme in example 1a, $(h^*, t_S^*) = (40, 20)$, is not implementable (in the absence of any side payment).

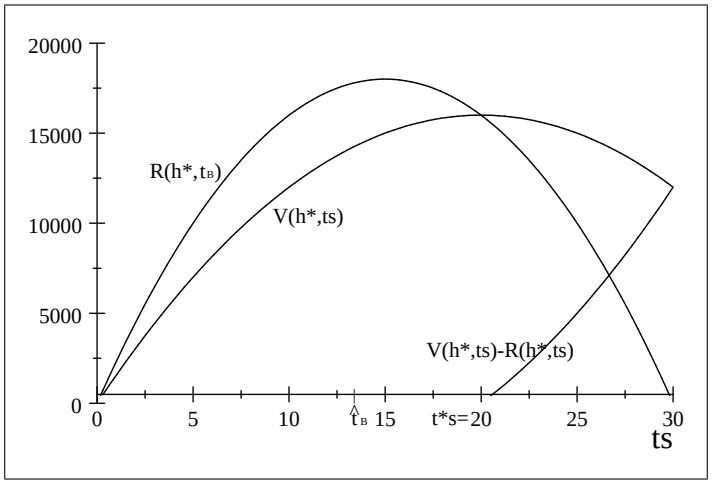

Fig. 1: Case where the local firm breaks away before the first best

transfer-stopping time.

$$\left(\widehat{t}_B\left(h^*\right) < t_S^*\right)$$

$$\left(T = 30,\ \gamma = 1,\ \alpha = 2,\ c = 1,\ K = 2,\ h = h^* = 20\right).$$

Using the parameters of example 1c condition (28) becomes $t_S \leq 15$. This shows that the first-best scheme in example 1c, $(h^*, t_S^*) = (39, 10)$ is implementable (but the multinational does not get the profit that it would get if the joint venture were a wholly owned subsidiary). The local firm will break away at time $\widehat{t}_B\left(h^*\right) = t_S^* = 10$.

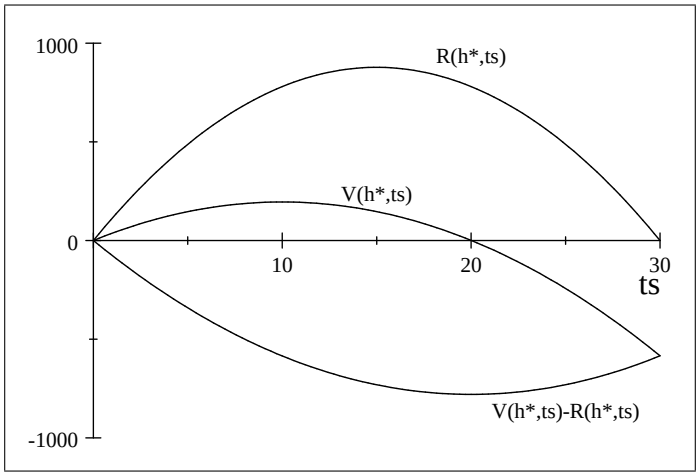

Fig. 2: Case where the local firm breaks away at the first best transfer-stopping time $\left(\widehat{t}_B\left(h^*\right) = t_S^* = 10\right)$.

$$\left(T = 30,\ \gamma = 1,\ \alpha = \tfrac{5}{4},\ c = 1,\ K = 0.1,\ h = h^* \simeq 39\right)$$

Figure 2 illustrates the case where the local firm would prefer that the transfer stops later than the first-best stopping-time, so that when it breaks away it will get a higher stock of knowledge. The local firm's preferred transfer stopping-time is $t = 15$. But, since the multinational chooses to stop the technology transfer at $t_S^* = 10$, the local firm has an incentive to break away at the same time.

3.3 Incentive compatible contract under credit constraint

Given that the local firm must have non-negative cash flow at all time, and that, in the absence of transfer payment from the multinational, it can secure the profit $\underline{V}_L(h) = (T - \widehat{t}_B(h))\pi(h\widehat{t}_B(h))$ by breaking away at an optimal day, the multinational firm must design a contract (with transfer payments) that maximizes its payoff, subject to the constraint that the local firm earns at least $\underline{V}_L(h)$.

In the absence of side payments, if the local firm stays with the joint venture until a later date $t_B^C > \widehat{t}_B(h)$, it loses an amount $\underline{V}_L(h) - (T - t_B^C)\pi(ht_B^C)$. Therefore, if the multinational wishes to induce the local firm to break away no sooner than t_B^C, it has to pay the local firm a compensation F equal to the loss of delaying the breakaway, $\underline{V}_L(h) - (T - t_B^C)\pi(ht_B^C)$.

More precisely, given any desired date $t_B^C > \widehat{t}_B(h)$, we can show that there exists a multiplicity of flows of side payments $w^C(.)$ (see Appendix 3) such that (a) the local firm, responding to such incentives, will choose to break away at time t_B^C and (b) the total side payment is minimal with respect to the incentive constraint and the borrowing constraint. All these solutions satisfy

$$\int_0^{\widehat{t}_B(h)} w^C(t)\,dt = 0 \text{ and } \int_{\widehat{t}_B(h)}^{t_B^C} w^C(t)\,dt + (T - t_B^C)\pi(ht_B^C) = \underline{V}_L(h) \qquad (36)$$

These flows have the same present value. The only difference between the various incentive-compatible flows $w^C(.)$ is how the flow is spread out between $\widehat{t}_B(h)$ and t_B^C. The intuition is as follows.

Firm M (the multinational) can offer to pay firm L (the local firm) a lump sum F at a contractual time t_B^C if L actually breaks away at time t_B^C or at any later date, so that firm L's total payoff is $F + (T - t_B^C)\pi(ht_B^C)$. If L breaks away at any time t_B before t_B^C, it will simply get the payoff $R(h, t_B) = (T - t_B)\pi(ht_B)$. Since L can always ensure the payoff $\underline{V}_L(h)$ by breaking away at time $\widehat{t}_B(h)$, firm M's offer would be accepted only if $F + (T - t_B^C)\pi(ht_B^C) \geq \underline{V}_L(h)$.

Alternatively, instead of giving the lump sum F at the time t_B^C, firm M can spread the payment of this total amount over time, from time $\widehat{t}_B(h)$ to time t_B^C, and still ensure that firm L has no incentive to break away before t_B^C. Recall that

$F = \underline{V}_L(h) - R(h, t_B)$, and that $R(h, t_B)$ is decreasing in t_B for all $t_B > \widehat{t}_B(h)$. So, for any sequence of dates $\{t_1 < t_2 < t_3 < ... < t_n\}$ where $\widehat{t}_B(h) < t_1 < t_n = t_B^C$, it holds that

$$\begin{aligned} F &= [\underline{V}_L(h) - R(h, t_1)] \\ &\quad + [R(h, t_1) - R(h, t_2)] + ... + [R(h, t_{n-1}) - R(h, t_n)] \qquad (37) \\ &\equiv F_1 + F_2 + .. + F_n \qquad (38) \end{aligned}$$

where each F_i is positive. Firm M can then offer the following contract to firm L: I will pay you F_i at time t_i if up to time t_i you are still part of the joint venture. Clearly, breaking away at any time $t \leq t_B^C$ does not give firm L any advantage in comparison to staying in the joint venture until time t_B^C.

The above argument supposes that payments are made in small amounts at a large number of discrete points of time. We can take the limit as the size of these time intervals go to zero, and n goes to infinity. This yields a continuous flow $w^C(t)$ such that $w^C(t) = -\frac{dR(h,t)}{dt} > 0$ for $t \in (\widehat{t}_B(h), t_B^C]$. Remark that this flow is increasing in t because $R(h, t)$ is concave in t, $\frac{dw^C(t)}{dt} = -\frac{d^2R(h,t)}{dt^2} > 0$.

All the above side transfer payments schemes have the same effect on the local firm's quitting time. We can therefore focus, without loss of generality, on the following particular flow of side payments (which concentrates at a point of time, i.e. the flow becomes a mass). The multinational offers to pay the local firm a lump sum amount $F \geq 0$ if the latter breaks away at a specified time t_B^C . Since the multinational does not want to overpay the local firm, the lump sum F will be just enough to make the local firm indifferent between (a) breaking away at $\widehat{t}_B(h)$ thus earning the secured pay-off $\underline{V}_L(h)$, and (b) breaking away at the contractual breakaway time t_B^C, thus earning $F + \left[T - t_B^C\right] \pi(ht_B^C)$. Thus $F + \left[T - t_B^C\right] \pi(ht_B^C) = \underline{V}_L(h)$. Therefore the side payment written in the contract is

$$\widetilde{w}(t_B) = \begin{cases} 0 & \text{if } t_B < t_B^C \\ \underline{V}_L(h) - \left[T - t_B^C\right] \pi(ht_B^C) & \text{if } t_B = t_B^C \end{cases} \qquad (39)$$

Let us now make use of the incentive constraint (39) to determine the multi-

national's optimal choice of both h and t_B^C to maximize its own payoff:

$$\widetilde{V}_M = \int_0^{t_B^C} [\pi(ht) - C(h)]\, dt + \left[T - t_B^C\right] \pi(ht_B^C) - \underline{V}_L(h) \tag{40}$$

The first order condition with respect to t_B^C is

$$\frac{\partial \widetilde{V}_M}{\partial t_B^C} = (T - t_B^C) h^C \pi'(h^C t_B^C) - C(h^C) = 0 \tag{41}$$

This condition has the same form as the first best condition (see equation (9)), except of course the value h is in general not the same. The first order condition with respect to h is

$$\frac{\partial \widetilde{V}_M}{\partial h} = \frac{\partial V}{\partial h} - \frac{\partial \underline{V}_L(h)}{\partial h} = 0 \tag{42}$$

or

$$\begin{aligned} \int_0^{t_B^C} \left[\tau \pi'(h^C \tau) - C'(h^C)\right] d\tau + (T - t_B^C) \pi' \left(h^C t_B^C\right) t_B^C \\ - \left[T - \widehat{t}_B(h^C)\right] \pi'(h^C \widehat{t}_B(h^C)) \widehat{t}_B(h^C) = 0 \end{aligned} \tag{43}$$

Example 3: Using the parameters of example 1b, $\widehat{t}_B\,(h) = 10$, then $\underline{V}_L(h) = 40\sqrt{10h}$.

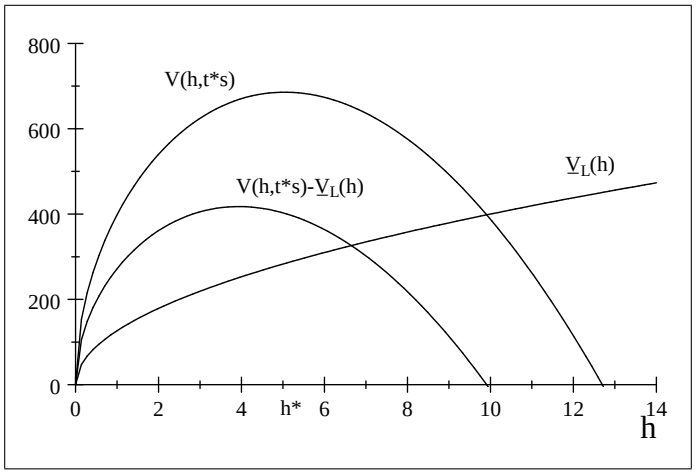

Fig. 3: The secure value of the local firm and the pace of technology transfer.

$$(T = 30,\ \gamma = 1,\ \alpha = \tfrac{1}{2},\ c = 1,\ K = 2,\ t = t_S^* = 18)$$

Figure 3 illustrates that, given the first best transfer-stopping time $t_S^* = 18$, if the local firm can secure $\underline{V}_L(h)$ (which is increasing in h), the multinational has an incentive to **reduce the pace of technology transfer to** $h_s \simeq 3.93$ lower than $h^* \simeq 5.04$.

3.4 Comparison with the first best

In this sub-section, we show that the second-best scheme described above implies that the multinational will choose a slower transfer rate $h^C < h^*$ and the cumulative technology transfer is also lower. We prove this for the general case (where the profit function $\pi(H)$ is concave), and provide an explicit solution for the case of a linear profit function $\pi(H) = KH$, $K > 0$ in Appendix 3.

First, let us show that the two equations (41) and (43) yield (h^C, t_B^C) with $h^C < h^*$ and $t_B^C > t_S^*$, where (h^*, t_S^*) is the solution of the system of first order conditions in the first best case studied in Section 2. For easy reference, we reproduce that system below:

$$\frac{\partial V_M}{\partial t_S} = \int_0^{t_S^*} \left[\tau\pi'(h^*\tau) - C'(h^*)\right] d\tau + (T - t_S^*)\pi'\left(h^* t_S^*\right) t_S^* = 0 \tag{44}$$

$$\frac{\partial V_M}{\partial t_S} = (T - t_S^*)h^*\pi'(ht_S^*) - C(h^*) = 0 \tag{45}$$

To show that $h^C < h^*$ and $t_B^C > t_S$, we use the following method. Let δ be an indicator, which can take any value between zero and 1. Consider the following system of equations:

$$\begin{aligned} W_1 \equiv \int_0^t \left[\tau\pi'(h\tau) - C'(h)\right] d\tau + (T - t)\pi'\left(ht\right) t \\ -\delta\left[T - \widehat{t}_B(h)\right]\pi'(h\widehat{t}_B(h))\widehat{t}_B(h) = 0 \end{aligned} \tag{46}$$

$$W_2 \equiv (T - t)h\pi'(ht) - C(h) = 0 \tag{47}$$

Clearly, if $\delta = 1$, the system (46)-(47) is equivalent to the system of equations

(41)-(43) and thus yield $(h,t) = (h^C, t_B^C)$, and if $\delta = 0$, the system (46)-(47) is equivalent to the system of equations (45)-(44) and thus yield $(h,t) = (h^*, t_S^*)$. For an arbitrary $\delta \in [0,1]$, the solution of the system is denoted by $\left(\widetilde{h}(\delta), \widetilde{t}(\delta)\right)$.

We now show that $\widetilde{h}(\delta)$ is decreasing in δ and $\widetilde{t}(\delta)$ is increasing in δ**.** Let W_{11} be the partial derivative of W_1 with respect to h, W_{22} be the partial derivative of W_2 with respect to t, W_{12} be the partial derivative of W_1 with respect to t, etc. Then we have the following system of equations:

$$\begin{bmatrix} W_{11} & W_{12} \\ W_{21} & W_{22} \end{bmatrix} \begin{bmatrix} d\widetilde{h} \\ d\widetilde{t} \end{bmatrix} = \begin{bmatrix} -W_{1\delta} \\ 0 \end{bmatrix} d\delta \tag{48}$$

Then

$$\frac{d\widetilde{h}}{d\delta} = \frac{-W_{1\delta}W_{22}}{W_{11}W_{22} - W_{21}W_{12}} \tag{49}$$

$$\frac{d\widetilde{t}}{d\delta} = \frac{W_{1\delta}W_{21}}{W_{11}W_{22} - W_{21}W_{12}} \tag{50}$$

Now, by the second order condition, $W_{11}W_{22} - W_{21}W_{12} > 0$. Hence $d\widetilde{h}/d\delta$ is negative if and only if $-W_{1\delta}W_{22} < 0$

Now

$$W_{1\delta} = -\left[T - \widehat{t}_B(h)\right] \pi'(h\widehat{t}_B(h))\widehat{t}_B(h) < 0 \tag{51}$$

and by the second order condition $W_{22} < 0$. This proves that $\widetilde{h}(\delta)$ is decreasing in δ.

We now show that $W_{21} < 0$, where

$$W_{21} = -C' + (T-t)(ht\pi'' + \pi') \tag{52}$$

Using (47),

$$-C' + (T-t)\pi' = -C' + \frac{C(h)}{h} < 0 \tag{53}$$

where the strict inequality follows from the assumption on $C(h)$: average cost is smaller than marginal cost. It follows that $W_{21} < 0$. This proves that $\widetilde{t}(\delta)$ is increasing in δ.

The quantity of technology transferred: Let us compare the total quantity

of technology transfer in the first best case $H^* \equiv h^* t_S^*$ and the quantity in the second best case $H^C \equiv h^C t_B^C$. Let $\widetilde{H}(\delta) \equiv \widetilde{h}(\delta)\widetilde{t}(\delta)$. Then

$$\frac{d\widetilde{H}(\delta)}{d\delta} = \frac{d\widetilde{h}(\delta)}{d\delta} \times \widetilde{t}(\delta) + \frac{d\widetilde{t}(\delta)}{d\delta} \times \widetilde{h}(\delta). \tag{54}$$

Using (49) and (50)

$$\frac{d\widetilde{H}}{d\delta} = \frac{-W_{1\delta}}{W_{11}W_{22} - W_{21}W_{12}} \left[\widetilde{t}W_{22} - \widetilde{h}W_{21}\right]. \tag{55}$$

Since $-W_{1\delta} > 0$ and $W_{11}W_{22} - W_{21}W_{12} > 0$, $d\widetilde{H}/d\delta$ is negative if and only if $\left[\widetilde{t}W_{22} - \widetilde{h}W_{21}\right]$ is negative. This term can be rewritten as

$$\widetilde{t}W_{22} - \widetilde{h}W_{21} = \widetilde{H}\left[-\pi' + (T - \widetilde{t})\widetilde{h}\pi''\right] - \widetilde{h}\left[(T - \widetilde{t})\left(\widetilde{H}\pi'' + \pi'\right) - C'\right] \tag{56}$$

Then

$$\widetilde{t}W_{22} - \widetilde{h}W_{21} = \widetilde{h}\left[C' - (T - \widetilde{t})\pi' - \widetilde{t}\pi'\right]. \tag{57}$$

Using assumption A3 ($\pi'(H) + H\pi''(H) \geqslant 0$ for all $H \geqslant 0$) we have

$$\frac{1}{\widetilde{t}}\int_0^{\widetilde{t}} \left[\tau\pi'(\widetilde{h}\tau)\right] d\tau \leq \widetilde{t}\pi'(\widetilde{H}). \tag{58}$$

Using (46) we obtain

$$\widetilde{t}\pi'(\widetilde{H}) \geq C'(\widetilde{h}) - (T - \widetilde{t})\pi'\left(\widetilde{H}\right) + \frac{\delta}{\widetilde{t}}\left[T - \widehat{t}_B(\widetilde{h})\right]\pi'(\widetilde{h}\widehat{t}_B(\widetilde{h}))\widehat{t}_B(\widetilde{h}). \tag{59}$$

Then, if $\delta > 0$

$$\widetilde{t}\pi'(\widetilde{H}) > C'(\widetilde{h}) - (T - \widetilde{t})\pi'\left(\widetilde{H}\right). \tag{60}$$

Using this inequality and (57) we conclude that, for $\delta > 0$,

$$\widetilde{t}W_{22} - \widetilde{h}W_{21} < 0. \tag{61}$$

This proves that $H^C < H^*$.

The following proposition summarizes the finding of this section:

Proposition 2: *To counter the local firm's opportunistic behavior, the multinational firm designs a second best scheme that involves a slower rate of technology transfer (thus reducing the local firm's secure payoff) and a lower total cumulative technology transfer. It also offers side payments to the local firm to delay the breakaway time. The side payments can be in the form of a continuous flow that increases with time, or a lump sum payable at a contracted breakaway time.*

Example 4: Use the parameters of example 1a.

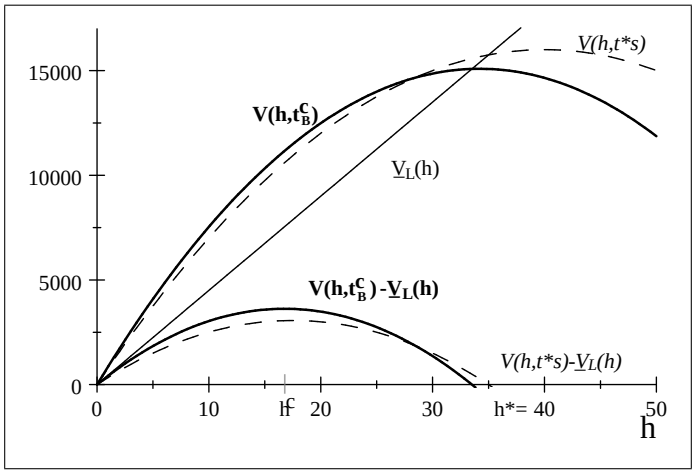

Fig. 4: The secure value of the local firm and the pace of technology transfer.
($T = 30$, $\gamma = 1$, $\alpha = 2$, $c = 1$, $K = 2$)

Figure 4 shows that the maximum joint profit is smaller in the second-best scheme (see the two curves at the top of figure 4**,** from the dash curve to the thick curve). To counter the local firm's incentive to quit early (at $\widehat{t}_B(h^*) = 10$), the multinational firm reduces the pace of technology transfer from $h^* = 40$ to $h^C \simeq 16.8$ (see the two curves at the bottom of figure 3, from the dash curve to the thick curve) while increasing the technology transfer stopping time from $t_S^* = 20$ to $t_B^C \simeq 25.8$. In this case, the multinational firm gets $V\left(h^C, t_B^C\right) - \underline{V}_L\left(h^C\right)$.

4 Implementation of first-best technology transfer with one market imperfection

In this section, we briefly indicate that if we relax one of the two assumptions C1 or C2, there exists a contract which implements the first best technology transfer.

Case A: Perfect credit market and no compensation payment after the breakaway

Assume that the local firm is not liable to make compensation payments after the breakaway time, i.e. C2 holds: $\phi(t) = 0$ for all t between t_B and T. The multinational asks the local firm to pay it up-front the value of the joint venture, $V(h^*, t_S^*)$, and gives the local firm the right to collect at each point of time t in $(0, t_S^*)$ the net cash flow $\pi(h^*t) - C(h^*)$. Hence the local firm's breakaway at time t_S^* as it has to solve the first best program.

Case B: Imperfect credit market and compensation payment must be made after the breakaway

In this case, the multinational pays the losses from 0 to $t^+(h)$,

$$\int_0^{t^+(h)} [\pi(h^*t) - C(h^*)]\, dt < 0, \tag{62}$$

and gives the local firm the right to collect the positive cash flow $\pi(h^*t) - C(h^*)$ for all t between $t^+(h)$ and t_S^*. In return, the local firm must, during the phase $[t^+(h), T]$, pay gradually to the multinational the total amount $V(h^*, t_S^*) - \int_0^{t^+(h)} [\pi(h^*t) - C(h^*)]\, dt$ in such a way that the local firm's net cash flow is non-negative at each point of time.

5 Implications of tariff policies, wages policies and spillover effects

5.1 Tariff policies and wages policies

Our model can be regarded as a reduced form version of a model with richer details and implications on tariff policies and wage policies. To see this, suppose that the joint venture sells in the local market a product for which a perfect substitute is available at the price $p = (1+\theta)p^I$ where p^I is the exogenously given world price and θ is the tariff rate. The output of the joint venture is a Cobb-Douglas function of two inputs, technology H and labor L. Assume that labor earns a constant wage rate w (equal to the wage in the alternative employment, say subsistence agriculture). Given $H(t)$, the joint venture chooses $L(t)$ to maximize instantaneous profit

$$\Pi(H, L) = (1 + \theta)p^I H^\beta L^{1-\beta} - wL \tag{63}$$

This yields the labor demand function

$$L = \left[\frac{(1 + \theta)p^I}{w}\right]^{1/\beta} H \tag{64}$$

Substituting this into the profit function Π, we get

$$\Pi = \left[(1 + \theta)p^I\right]^{1/\beta} \left(\frac{1 - \beta}{\beta}\right) w^{1-(1/\beta)} H \tag{65}$$

It follows that our K in example 1 is

$$K = \left[(1 + \theta)p^I\right]^{1/\beta} \left(\frac{1 - \beta}{\beta}\right) w^{1-(1/\beta)} \tag{66}$$

An increase in the tariff rate will raise K which leads to an increase in both the pace of transfer h^* and the aggregate technology transfer $h^* t_S^*$ in the first-best transfer scheme. The second best amount of transfer also increases, because K increases (see Appendix 3). Similarly, a smaller wage rate will lead to more technology transfer.

A developing country must consider the trade-off between the static efficiency loss of a tariff and the dynamic gain generated by technology transfer (and its spillover effects).

5.2 Spillover effects in a Cournot duopoly

Our model can also be regarded as a reduced form version of a model of Cournot competition with spillover effects. Suppose that there are two local firms, denoted by L (the local firm which forms the joint venture with the multinational) and l. The two firms compete à la Cournot and the inverse demand function is linear, $p(Q) = a - Q$, $a > 0$. The quantities they produce are respectively denoted q_L and q_l. Assume that the technology transferred is cost-reducing. When firm L has accumulated an amount of technology H, its marginal cost is $c_L(H) = a - r(H)$, with $a \geq r(h_{\max}T)$. The second local firm l benefits from spillover effects. Its marginal cost is $c_l(H) = a - \beta r(H)$, where β is the strength of the spillover effects. For simplicity, assume that $r(H) = \sqrt{bH}$, $b > 0$. The profits of the local firms L and l are, respectively

$$\Pi_L(H, q_L, q_l) = (r(H) - q_L - q_l) q_L, \tag{67}$$

and

$$\Pi_l(H, q_L, q_l) = (\beta r(H) - q_L - q_l) q_l. \tag{68}$$

Now assume that $\beta \in \left[\frac{1}{2}, 1\right]$. Under this assumption, both firms produce in equilibrium. The equilibrium quantities are

$$q_L^* = \frac{1}{3}(2 - \beta)\sqrt{bH} \text{ and } q_l^* = \frac{1}{3}(2\beta - 1)\sqrt{bH}. \tag{69}$$

Substituting these quantities in the profit functions, we get

$$\Pi_l(H, q_L^*, q_l^*) = \frac{1}{9}(2\beta - 1)^2 bH, \tag{70}$$

and

$$\Pi_L\left(H, q_L^*, q_l^*\right) = \frac{1}{9}\left(2-\beta\right)^2 bH. \tag{71}$$

The profit function of the local firm L is the same as in example 1 with

$$K = \frac{1}{9}\left(2-\beta\right)^2. \tag{72}$$

An increase in the strength of spillover effects β will reduce K which leads to a decrease in both the pace of technology transfer h^* and the aggregate technology transfer $H^* = h^* t_s^*$. The second best amount of technology transfer also decreases.

6 Concluding Remarks

Our model seems to be the first theoretical formulation of the problem of choice of the pace of technology transfer from a multinational firm to a joint venture in a host country. We have shown that when the host country cannot enforce joint venture contract, the multinational will have an incentive to reduce the pace of technology transfer and the cumulative amount of technology transfer.

A major implication of our model is that if the host country's legal system is not sufficiently strong to prevent breakaway by local firms**,** the multinational will reduce the rate of technology transfer. To the extent that technology transfers in one industry have positive spillover effects to other industries in the host country, this country loses out by its inability to enforce contracts.

Our model can be used to examine the stability of relationships, such as employer-employee contracts, where the employee can learn from working in the firm and leave the firm once he has accumulated sufficient human capital.

Appendix

Appendix 1: Proof of Proposition 1

The choice set Ω defined by $\Omega = \{(h, t_S) : 0 \leq h \leq h_{\max} \text{ and } 0 \leq t_S \leq T\}$ is a compact set. The objective function (8) is continuous in the variables h, t_S over

the compact set Ω. By Weierstrass theorem, there exists a maximum, which we denote by (h^*, t_S^*).

Next, we show that the maximum must be in the interior of the admissible set Ω. Since $\pi(0) = C(0) = 0$ and $T\pi'(0) > C'(0) \geq 0$, the function $V(h, t_S)$ is strictly positive for some positive h sufficiently close to zero, for all t_S. Since $V(0, t_S) = 0$ and $V(h, 0) = 0$, it follows that the optimum must occurs at some $t_S^* > 0$ and $h^* > 0$. To prove (i) and (ii) above, it remains to show that an optimum cannot occur at any point on the line $t_S = T$ nor on the line $h = h_{\max}$. To take into account the constraints $T - t_S \geq 0$ and $h_{\max} - h \geq 0$, we introduce the associated Lagrange multipliers $\lambda \geq 0$ and $\mu \geq 0$. The Lagrangian is

$$L = \int_0^{t_S} [\pi(ht) - C(h)]\, dt + (T - t_S)\pi\left(ht_S\right) + \lambda(T - t_S) + \mu(h_{\max} - h) \quad \text{(A.1)}$$

The first order conditions are

$$\begin{gathered} \left[T - t_S^*\right] \pi'\left(h^* t_S^*\right) h^* - C(h^*) - \lambda = 0, \\ \lambda(T - t_S^*) = 0,\ \lambda \geq 0,\ T - t_S^* \geq 0, \end{gathered} \quad \text{(A.2)}$$

$$\begin{gathered} \int_0^{t_S} [t\pi'(h^* t) - C'(h^*)]\, dt + (T - t_S^*)\pi'\left(h^* t_S^*\right) t_S^* - \mu = 0, \\ \mu(h_{\max} - h) = 0,\ \mu \geq 0,\ h_{\max} - h^* \geq 0 \end{gathered} \quad \text{(A.3)}$$

Since $C(h^*) > 0$, condition (A.2) implies that $T - t_S^* > 0$. (The intuition behind this result is simple: there is no point to transfer technology near the end of the time horizon T). Thus $\lambda = 0$ and hence (A.2) reduces to

$$(T - t_S^*)\pi'\left(h^* t_S^*\right) = \frac{C(h^*)}{h^*} \quad \text{(A.4)}$$

To show that $h^* < h_{\max}$, let us suppose that $h^* = h_{\max}$. Then, using (A.4), and

$h^* = h_{\max}$, condition (A.3) gives

$$C'(h_{\max})t_S^* - \frac{C(h_{\max})}{h^*}t_S^* \leq C'(h_{\max})t_S^* - \frac{C(h_{\max})}{h_{\max}}t_S^* + \mu \tag{A.5}$$
$$= \int_0^{t_S} t\pi'(h_{\max}t)dt < \pi'(0)\int_0^{t_S} tdt = \frac{\pi'(0)(t_S^*)^2}{2}$$

which violates assumption A1. Thus $h^* < h_{\max}$. This concludes the proof that (h^*, t_S^*) is in the interior of Ω.

It follows that

$$\begin{aligned}\int_0^{t_S} \left[t\pi'(h^*t)\right] dt &= C'(h^*)t_S^* - (T - t_S^*)\pi'\left(h^*t_S^*\right) t_S^* \\ &= \left[C'(h^*) - \frac{C(h^*)}{h^*}\right] t_S^*\end{aligned} \tag{A.6}$$

It remains to verify the second order conditions. Recall that the FOCs at an interior maximum is

$$V_1 \equiv V_{t_S} = (T - t_S)\pi'\left(ht_S\right) h - C(h) = 0 \tag{A.7}$$

$$V_2 \equiv V_h = \int_0^{t_S} \left[t\pi'(ht)\right] dt + (T - t_S)\pi'\left(ht_S\right) t_S - t_S C'(h) = 0 \tag{A.8}$$

The SOCs are

$$V_{11} = -\pi'\left(ht_S\right) h + (T - t_S)\pi''\left(ht_s\right)(h)^2 < 0 \tag{A.9}$$

$$V_{22} = \int_0^{t_S} \left[t^2\pi''(ht)\right] dt - t_S C''(h) + (T - t_S)\pi''\left(ht_S\right)(t_S)^2 < 0 \tag{A.10}$$

$$\Delta \equiv V_{11}V_{22} - (V_{12})^2 > 0 \tag{A.11}$$

Clearly $V_{11} < 0$ and $V_{22} < 0$. It remains to check that $\Delta > 0$ at (t_S^*, h^*). Note that

$$V_{12} = (T - t_S)\pi''\left(ht_S\right) ht_S + \left[(T - t_S)\pi'\left(ht_S\right) - C'(h)\right] = \tag{A.12}$$

$$(T - t_S)\pi''\left(ht_S\right) ht_S + \left[\frac{C(h)}{h} - C'(h)\right] < 0 \tag{A.13}$$

(making use of (A.4)).

Consider the curve $t_S = \psi(h)$ defined by (A.7) in the space (h, t_S) where h is measured along the horizontal axis. The slope of this curve is

$$\psi'(h) = \frac{dt_S}{dh} \mid_{\psi} = -\frac{V_{12}}{V_{11}} < 0 \tag{A.14}$$

Along this curve

$$(T - t_S)\pi'(ht_S) = \frac{C(h)}{h} \tag{A.15}$$

as $h \to 0$, $t_S \to T$, and as $t_S \to 0$, $h \to \widetilde{h}$ where $\widetilde{h}$ is defined by $T\pi'(0) = \frac{C(\widetilde{h})}{\widetilde{h}}$.

Next consider the curve $t_S = \phi(h)$ defined by (A.8). The slope of this curve is

$$\phi'(h) = \frac{dt_S}{dh} \mid_{\phi} = -\frac{V_{22}}{V_{12}} < 0 \tag{A.16}$$

Along this curve

$$\int_0^{t_S} \left[\frac{t\pi'(ht)}{t_S\pi'(0)}\right] dt + (T - t_S)\frac{\pi'(ht_S)}{\pi'(0)} = \frac{C'(h)}{\pi'(0)} \tag{A.17}$$

As $h \to 0$, $t_S \to 2T$, and as $t_S \to 0$,$h \to \widehat{h}$ where $\widehat{h}$ is defined by $T\pi'(0) = C'\left(\widehat{h}\right)$. Since $C'(h) > C(h)/h$, it follows that $\widehat{h} < \widetilde{h}$. Thus the curve $\phi(h)$ must intersect the curve $\psi(h)$ from above (at least once). At that intersection, the slope of the $\phi(h)$ curve must be more negative (i.e. steeper) than the slope of the $\psi(h)$ curve, that is

$$-\frac{V_{22}}{V_{12}} < -\frac{V_{12}}{V_{11}} \tag{A.18}$$

hence

$$V_{11}V_{22} > (V_{12})^2 \tag{A.19}$$

Thus the SOC is satisfied at that intersection.

Finally, we can show that under assumption A3, the two curves $\phi(h)$ and $\psi(h)$ intersect exactly once, that is, we show that $\Delta > 0$ whenever the FOCS are satisfied. It is easy to see that A3 implies that $t\pi'(ht)$ is an increasing function of t.

We note the following facts. First,

$$(V_{12})^2 = [(T-t_S)\pi''(ht_S)\,ht_S]^2 + \left[\frac{C(h)}{h} - C'(h)\right]^2 + 2(T-t_S)\pi''(ht_S)\,ht_S\left[\frac{C(h)}{h} - C'(h)\right] \tag{A.20}$$

Secondly,

$$\begin{aligned} V_{11}V_{22} &> \left\{(T-t_S)\pi''(ht_S)\,(h)^2 - \pi'(ht_S)\,h\right\} && \text{(A.21)}\\ &\times \left\{(T-t_S)\pi''(ht_S)\,(t_S)^2 - C''(h)t_S\right\} && \text{(A.22)} \end{aligned}$$

$$= [(T-t_S)\pi''(ht_S)\,ht_S]^2 + C''(h)\pi'(ht_S)\,ht_S$$
$$-(T-t_S)\,\pi'(ht_S)\,\pi''(ht_S)\,h(t_S)^2 - C''(h)\pi''(ht_S)\,t_S(h)^2\,(T-t_S)$$

$$\begin{aligned} = \; & [(T-t_S)\pi''(ht_S)\,ht_S]^2 - (T-t_S)\,\pi''(ht_S)\,ht_S\,[\pi'(ht_S)\,t_S + hC''(h)] \\ & + C''(h)\pi'(ht_S)\,ht_S \end{aligned}$$

Hence

$$\Delta \geq -(T-t_S)\,\pi''(ht_S)\,ht_S\left[\pi'(ht_S)\,t_S + hC''(h) - 2\left(C'(h) - \frac{C(h)}{h}\right)\right] \tag{A.23}$$

$$+C''(h)\pi'(ht_S)\,ht_S - \left[\frac{C(h)}{h} - C'(h)\right]^2 \tag{A.24}$$

Using the implication of assumption A1 stated in (4), which can be written as $hC''(h) > \left(C'(h) - \frac{C(h)}{h}\right)$, we have

$$\begin{aligned} \Delta &> \left[\left(C'(h) - \frac{C(h)}{h}\right) - (T-t_S)\,\pi''(ht_S)\,ht_S\right] && \text{(A.25)}\\ &\times \left[\pi'(ht_S)\,t_S - \left(C'(h) - \frac{C(h)}{h}\right)\right]. && \text{(A.26)} \end{aligned}$$

It remains to show that $\pi'(ht_S)\,t_S \geqslant \left(C'(h) - \frac{C(h)}{h}\right)$.

With (A.6), we know that

$$\left[C'(h^*) - \frac{C(h^*)}{h^*}\right] t_S^* = \int_0^{t_S} \left[t\pi'(h^*t)\right] dt. \tag{A.27}$$

If A3 holds, $t\pi'(h^*t)$ is increasing in t (remark 1). Then

$$\pi'\left(ht_S\right) t_S \geqslant \int_0^{t_S} \left[t\pi'(h^*t)\right] dt, \tag{A.28}$$

We conclude that $\Delta > 0$.

Appendix 2: Consider the isoelastic profit function $\pi(H) = (1/\gamma)H^\gamma$ where $0 < \gamma < 1$. Then equation (31) gives a unique $\widehat{t}_B(h)$ that is independent of h :

$$(T - t_B)H^{\gamma-1}h = \frac{1}{\gamma}H^\gamma \tag{A.29}$$

so

$$TH^{\gamma-1}h = H^\gamma(1 + \frac{1}{\gamma}) \tag{A.30}$$

or

$$\frac{T}{t_B}H^{\gamma-1}ht_B = H^\gamma(1 + \frac{1}{\gamma}) \tag{A.31}$$

ie

$$H^\gamma \left[\frac{T}{t_B} - \frac{1+\gamma}{\gamma}\right] = 0 \tag{A.32}$$

then

$$\widehat{t}_B = \frac{\gamma}{1+\gamma}T \tag{A.33}$$

This is independent of h.

Appendix 3: The incentive compatible contract when $\pi(H)$ is linear.

The first order condition ((41) and (43))of the program can be rewritten as

$$K(T - t_B^C)h - C\left(h\right) = 0, \tag{A.34}$$

$$K\frac{\left(t_B^C\right)^2}{2} - t_B^C C'(h) + K(T - t_B^C)t_B^C - K\frac{T^2}{4} = 0. \tag{A.35}$$

Equivalently,

$$K(T-t_B^C)h - C\left(h\right) = 0, \tag{A.36}$$

$$K\frac{\left(t_B^C\right)^2}{2} + t_B^C\left[\frac{C\left(h\right)}{h} - C'(h)\right] - K\frac{T^2}{4} = 0. \tag{A.37}$$

Replacing $C\left(h\right) = \frac{c}{\alpha}h^{\alpha}$, we have

$$\left[K(T-t_B^C) - \frac{c}{\alpha}h^{\alpha-1}\right]h = 0, \tag{A.38}$$

$$K\frac{\left(t_B^C\right)^2}{2} - ct_B^C\left[1-\frac{1}{\alpha}\right]h^{\alpha-1} - K\frac{T^2}{4} = 0. \tag{A.39}$$

If $h > 0$

$$\alpha K(T-t_B^C) = ch^{\alpha-1}, \tag{A.40}$$

$$K\frac{\left(t_B^C\right)^2}{2} - ct_B^C\left[1-\frac{1}{\alpha}\right]h^{\alpha-1} - K\frac{T^2}{4} = 0. \tag{A.41}$$

Or,

$$\alpha K(T-t_B^C) = ch^{\alpha-1}, \tag{A.42}$$

$$K\frac{\left(t_B^C\right)^2}{2} - t_B^C\left[\alpha-1\right](T-t_B^C) - K\frac{T^2}{4} = 0. \tag{A.43}$$

The solution is:

$$t_B^C = \frac{\alpha - 1 + \sqrt{(\alpha-1)^2 + \alpha - 1/2}}{2\alpha-1}T, \tag{A.44}$$

$$\alpha K(T-t_B^C) = c\left(h^C\right)^{\alpha-1}. \tag{A.45}$$

The contractual breakaway time is

$$t_B^C = \frac{\alpha - 1 + \sqrt{(\alpha-1)^2 + (\alpha-0.5)}}{2\alpha-1}T > t_S^* = \frac{2(\alpha-1)}{2\alpha-1}T \tag{A.46}$$

This implies that

$$\frac{T - t_B^C}{T} = \frac{\alpha - \sqrt{(\alpha-1)^2 + (\alpha - 0.5)}}{2\alpha - 1} \equiv \frac{\mu}{2\alpha - 1} > 0 \tag{A.47}$$

where $\mu > 0$ and

$$\mu - 1 < 0 \tag{A.48}$$

The transfer rate is

$$h^C = \left[\frac{\alpha K (T - t_B^C)}{c}\right]^{1/(\alpha-1)} = \left[\frac{\alpha K \mu T}{(2\alpha - 1)c}\right]^{1/(\alpha-1)} < h^* \tag{A.49}$$

because $\mu < 1$.

The optimal lump sum F is

$$F^{**} = \underline{V}_L(h) - \left[T - t_B^C\right] \pi(h^C t_B^C) = \tag{A.50}$$

$$\left[T - \widehat{t}_B(h^C)\right] \pi(h^C \widehat{t}_B(h^C)) - \left[T - t_B^C\right] \pi(h^C t_B^C) \tag{A.51}$$

To prove that $F^{**} > 0$, it suffices to show that $\widehat{t}_B(h^C) < t_B^C$. Using Lemma 1, part (i), we know that $\widehat{t}_B(h^C) < t_B^C$ if $(T - t_B^C)\pi'(h^C t_B^C)h^C - \pi(h^C t_B^C) < 0$. Since π is linear, this condition reduces to

$$(T - t_B^C)h^C - t_B^C h^C < 0 \tag{A.52}$$

i.e.

$$T < 2t_B^C \tag{A.53}$$

This condition is satisfied, because, from (A.46)

$$\frac{t_B^C}{T} = \frac{\alpha - 1 + \sqrt{(\alpha-1)^2 + (\alpha - 0.5)}}{2\alpha - 1} > \frac{1}{2} \tag{A.54}$$

where the strict inequality follows from

$$2\sqrt{(\alpha-1)^2 + (\alpha - 0.5)} > 1 \tag{A.55}$$

i.e.

$$4\left[(\alpha-1)^2+(\alpha-0.5)\right]>1 \tag{A.56}$$

which is true because $\alpha > 1$.)

Appendix 4: Consider a given contractual breakaway time t_B^C with $t_B^C > \widehat{t}_B(h)$, where $\widehat{t}_B(h)$ is the "default breakaway time" found in Lemma 1, i.e., the time the local firm would choose to break away in the absence of the flow $w(.)$. Given t_B^C, the multinational will choose the minimal total flow of side payment that satisfies the incentive constraint, the participation constraint and the borrowing constraint. Formally, the multinational finds a function $w(.)$ that solves:

$$\min_{w(.)}\left[\int_0^{t_B^C} w(t)\,dt\right] \tag{A.57}$$

such that (a) the flow induces the local firm to choose t_B^C, i.e. such that

$$t_B^C=\arg\max_{t_B}\left[V_L=\int_0^{t_B} w(t)\,dt+(T-t_B)\pi(H(t_B))\right] \tag{A.58}$$

and (b) the side payment at any time t is non-negative, i.e.

$$0\le\int_0^t w(\tau)\,d\tau \text{ if } t\in\left[0,t_B^C\right]. \tag{A.59}$$

Let $w^C(.)$ denote a solution of this program.(We allow the function $w(t)$ to have a mass at isolated points.)

Lemma 2*: A flow of side payments $w^C(.)$ is optimal if and only if the following conditions are satisfied.*

(a) the local firm receives no payment prior to its "default breakaway time" $\widehat{t}_B(h)$:

$$\int_0^{\widehat{t}_B(h)} w^C(t)\,dt=0, \tag{A.60}$$

(b) the sum of the accumulated side payments and the local firm's stand-alone

profit after t_B^C just equals its secured profit $\underline{V}_L(h)$:

$$\int_0^{t_B^C} w^C(t)\,dt + (T - t_B^C)\pi(ht_B^C) = (T - \widehat{t}_B(h))\pi(h\widehat{t}_B(h)) \equiv \underline{V}_L(h) \tag{A.61}$$

(c) and, for any time t where $\widehat{t}_B(h) \leq t \leq t_B^C$, the total payoff to the local firm is inferior to its secured profit $\underline{V}_L(h)$:

$$0 \leq \int_{\widehat{t}_B(h)}^{t} w^C(\tau)\,d\tau \leq (T - \widehat{t}_B(h))\pi(h\widehat{t}_B(h)) - (T - t_B)\pi(ht_B) \tag{A.62}$$

Proof:

(i) Proof of sufficiency: It is easy to verify that when $w^C(.)$ satisfies conditions (A.60), (A.61) and (A.62) it is a solution of (A.57).

(ii) Proof of necessity: Consider a solution of (A.57). We show that it must satisfy conditions (A.60), (A.61) and (A.62).

To show the necessity of condition (A.61), suppose that $w^C(.)$ does not satisfy condition (A.61). If the left-hand side of (A.61) is strictly smaller than $\underline{V}_L(h)$, the local would not choose t_B^C and hence the incentive constraint (A.58) is violated. If the left-hand side of (A.61) is strictly greater than $\underline{V}_L(h)$, then the multinational can reduces it costs by offering less side payments.

Next, we show the necessity of condition (A.62). If $w^C(.)$ does not satisfy the left inequality of condition (A.62) then condition (A.59) is not satisfied. If $w^C(.)$ does not satisfy the right inequality part of condition (A.62), then there exists $\widetilde{t}_B$ within the interval $\left[\widehat{t}_B(h), t_B^C\right]$ such that

$$\int_{\widehat{t}_B(h)}^{\widetilde{t}_B} w^C(t)\,dt > (T - \widehat{t}_B(h))\pi(h\widehat{t}_B(h)) - (T - \widetilde{t}_B)\pi(h\widetilde{t}_B) \tag{A.63}$$

From the incentive constraint (A.58), from the local firm's point of view, by definition of t_B^C, $\widetilde{t}_B$ does not dominate t_B^C, i.e.

$$\int_{\widetilde{t}_B}^{t_B^C} w^C(t)\,dt \geq (T - \widetilde{t}_B)\pi(h\widetilde{t}_B) - (T - t_B^C)\pi(H(t_B^C)) \tag{A.64}$$

Adding inequalities (A.63) and (A.64) we have

$$\int_0^{t_B^C} w^C(t)\,dt+(T-t_B^C)\pi(H(t_B^C)) > \int_0^{\widehat{t}_B(h)} w^C(t)\,dt+(T-\widehat{t}_B(h))\pi(h\widehat{t}_B(h)) \quad \text{(A.65)}$$

Thus $w^C(.)$ fails to minimize the total flow of side payments $\int_0^{t_B^C} w^C(t)\,dt$.

Finally, we show the necessity of (A.60). Suppose that $w^C(.)$ does not satisfy condition (A.60), i.e.

$$\int_0^{\widehat{t}_B(h)} w^C(t)\,dt > 0, \quad \text{(A.66)}$$

Using the incentive constraint (A.58), we obtain

$$\begin{aligned}\int_0^{t_B^C} w^C(t)\,dt + (T-t_B^C)\pi(H(t_B^C)) &\geq \int_0^{\widehat{t}_B(h)} w^C(t)\,dt + (T-\widehat{t}_B(h))\pi(h\widehat{t}_B(h)) \\ &> (T-\widehat{t}_B(h))\pi(h\widehat{t}_B(h)) \quad \text{(A.67)}\end{aligned}$$

This implies that $w^C(.)$ does not minimize the total flow of side payments $\int_0^{t_B^C} w^C(t)\,dt$.

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