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Joint Venture Breakup and the Exploration-Exploitation Trade-off

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Abstract

This paper explores the effect of a potential joint-venture breakup on the level of technology transfer in a set-up with exploration-exploitation trade-offs in the presence of time compression costs. We consider a 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, and the local firm can quit without penalties. The multinational firm has to consider the advantages and disadvantages of an intensive transfer of technology versus an extensive one. In response to the breakup incentives, the multinational firm reduces the intensity (lowering the pace) and opts for a more extensive transfer mode (longer duration of transfer), compared to the first best. The scheme is supported by a flow of side payments to encourage the local firm to stay longer. We show that a fall in time compression costs may increase or decrease the intensity of technology transfer, both in the first-best and in the second-best scenarios, depending on the nature of the saving in time-compression costs.

JEL Classification: **F23, D23, O33,O34**

Key words: Technology transfer, joint venture, absorptive capacity, time-compression cost, breakup of relationship

1 Introduction

Technology transfer from developed economies to less developed ones has been an important engine of growth of emerging market economies. A common mode of technology transfer is the setting up of a joint venture between a multinational and a local firm[1]. 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 breakup typically happens within a few years. The local partner 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 has been widely reported. 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.).

This paper considers the effect of an anticipated breakup on the manipulation of actual breakup time via distorting the level of technology transfer. We assume the multinational firm always honors its promises (because it wants to maintain its reputation in other countries), but it cannot prevent the local firm from breaking away after receiving technology transfer.

The problem for the multinational firm is to give an incentive to the local firm to stay longer, because after the breakup, it will be obliged to stop production in the host country, while the local firm will gain by using the acquired knowledge as a stand-alone firm. Incentives for the local partner to stay longer can be either in the form of a large flow of side payments or a promised increase in the transfer of knowledge before the break (which, if not well-designed, can become itself an incentive to leave sooner). In the first case, the local

[1] 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.

firm will benefit a lot before the breakup, while in the second case the local firm will reap a large profit after the breakup. In this context, within a fixed horizon, a first key feature of our model is to know how the multinational will balance between an intensive and an extensive mode of knowledge transfer. Given a total amount of knowledge to be transferred, at one extreme one can choose a highly intensive transfer mode (a fast rate of transfer over a short period of time) and at the other extreme, one can opt for an extensive transfer mode (a slow transfer rate over a long period of time). Then, if the transfer of knowledge is too intensive, the local firm will quit sooner to benefit alone, for a longer time, of a large total amount of knowledge accumulated before the breakup. In this case the profit for the multinational will be of short duration. Furthermore, the breakup time being not contractible, the multinational firm may have to rely on second-best technology transfer schemes that do not maximize joint surplus, but that are incentive compatible.

In our model three key features of technology transfer play a major role: it is costly, it takes time and it generates value.

i) it is costly: the faster the pace of knowledge transfer, the more costly it is. Indeed, there are "time-compression costs" (Dierickx and Cool,1989) and absorptive capacity costs (Cohen and Levinthal,1990). For a given total amount of knowledge to be transferred, the shorter the interval of time the multinational spends to transfer it, the greater will be its transfer cost.

ii) it takes time: time is an essential element here. The earlier the breakup, the more time would be available for the local firm to reap the rewards of value creation, and the shorter is the phase of positive profit for the multinational. This is a specific form of the famous "exploration-exploitation" trade-off (March,1991) where the opportunity cost of exploring (learning) is the reduced time for exploitation for the fully acquired knowledge[2]. In our model, exploration represents, for each unit of time until the breakup, a transfer of knowledge, while exploitation is the ability to reap some profit. The multinational will not be able to exploit after the breakup, while the local firm can exploit both before and after the breakup. The resolution of this trade-off, the right balance between exploration and exploitation, depends on what type of knowledge is involved: knowledge in the sense of information ("to know what"), or knowledge in the sense of ability to act ("to know how", learning by doing or

[2] March defined exploration and exploitation as follows: "Exploration includes things captured by terms such as search, variation, risk taking, experimentation, play, flexibility, discovery, innovation. Exploitation includes such things as refinement, choice, production, efficiency, selection, implementation, execution" (1991, p. 71). Levinthal and March added that exploration involves "a pursuit of new knowledge," whereas exploitation involves "the use and development of things already known" (1993, p. 105). In general exploration means learning (by imagination, evaluation, building competences and human capital, by imitation or introspection). In our case it represents a transfer of knowledge.

by thinking). Knowledge can be more or less tacit. To be able to use it an agent can imitate the "teacher", or the teacher must codify the knowledge to be transferred, changing tacit knowledge into explicit knowledge. There is also the need for a preparation phase (building absorptive capacities). The costs of transferring knowledge include costs of achieving mutual understanding, of improving assimilation capabilities, codification costs, etc.

iii) it generates value: the more knowledge the multinational transfers before the breakup, the larger is the joint profit per unit of time before the breakup, and the larger is the stand-alone profit of the local firm after the breakup.

In this dynamic context, our paper explores the effect of a potential joint-venture breakup on the level of technology transfer in a set-up with exploration-exploitation trade-offs in the presence of time compression costs and imperfect property rights. Thus, supported by a side-payment scheme, the nature of transfer costs will determine the optimal intensive vs. extensive mode of transfer, the total amount of knowledge transferred before the breakup and the optimal breakup time.

We will compare the first-best and second-best cases by asking the following questions: (i) if 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 to give an incentive to delay the breakup ? (iv) How do exogenous changes in transfer cost impact the time profile of transfer ?

In response to breakup incentives, we show that the multinational firm transfers technology in a less intensive but more extensive way compared to the first-best. The scheme is supported by a flow of side payments to encourage the local firm to stay longer. We show that a fall in time compression costs may increase or decrease the intensity of technology transfer, both in the first-best and in the second-best scenarios, depending on the nature of the time compression costs economies, the length of the time horizon and on the maximum absorptive capacity.

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 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.

Our model is linked to two streams of the literature. The first one focuses on the definition and properties of the costs of technology transfer, while the second stream, typically relying on two-period formulation, concerns the technology transfer within a joint venture.

Our assumptions on the costs of technology transfer are based on empirical findings. 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 local firm. 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". Niosi et al. (1995) found that technology transfer costs are significant and mostly concentrated in training. A central aspect of our model consists of exploring the implications of the time-compression cost of technology transfer. The following specific example illustrates. Take the transfer cost function $C(h) = b(h/\overline{h})^{\alpha}$ where $0 \leq h \leq \overline{h}$ is the amount of transfer per unit of time, and $\alpha \geq 1$ is the degree of convexity. A strictly convex cost ($\alpha > 1$) means marginal cost of transfer increases with h. The parameter α represents an index of time compression[3]. We show how an increase in α (which may come about from

[3] See Attouch and Soubeyran (2006, 2008).

exogenous changes in communication technology) may affect the equilibrium transfer rate in the first-best (perfect property rights) and in the second-best (imperfect property rights) scenarios. We also examine a fall in b which represents a global fall in the time-compression cost. Results on the impact of a fall in transfer cost on the equilibrium amount of technology transfer differ, depending on whether a such a fall is caused by a rise in α or by a fall in b. Then, in modelling the endogenous pace and duration of technology transfer, our paper, by seriously taking into account "time-compression costs", provides a useful framework to investigate theoretical support for the hypothesis that the degree of intellectual property protection influences the extent of technology transfer (for a survey of empirical evidence, see Mansfield, 1994).[4]

The second major contribution of our model is an explicit account of the incentive problem of technological transfer in a dynamic setting. This topic has been considered by Ethier and Markusen (1996), Markusen (2001), and Roy Chowdhury and Roy Chowdhury (2001) using two-periods models. The questions we wish to address, namely the determination of the optimal and second-best pace of technology transfer, cannot be examined adequately in a two-period model. With just two periods, one cannot model the "spreading" effect (transferring knowledge over a longer period of time) and the effect of a reduction in transfer cost on the timing and amount of technology transfer. Our model, set in continuous time, is capable of generating a richer set of results. It enables us to show how to achieve the balance between the intensive and the extensive modes of transfer, and to determine jointly the optimal length of the transfer phase and the optimal total amount of knowledge to be transferred (both in the first-best case and the second-best cases). Furthermore, our result on non-monotonicity of the local firm's value of quitting as a function of quitting time cannot be obtained in two-period models. This non-monotonicity has important bearing on the principal's optimal speed of technology transfer. There are two important considerations here. On the one hand, first-best efficiency requires trading off higher absorption cost associated with faster transfer against higher benefit of knowledge accumulation. On the other hand, a high speed of transfer brings the local firm's optimal quitting time closer to the present, which is detrimental to the multinational.

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.[5] The winning firm

[4] By emphasizing the time-compression cost, our model differs significantly from the licensing models (e.g. Kabiraj and Marjit (2003), Mukherjee and Pennings (2006)) in which technology transfer is via licensing, which does not use up real resources.

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

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 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 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. A main result is that if contract enforcement induces a shift from exporting to local production, 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 multi-period agency contract between a multinational firm and a local agent 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.

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.[6] 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 shows how an exogenous fall in transfer costs (e.g. because of reduced barriers to communication) affects the equilibrium transfer rate as well as the total amount of transfer. The Appendices contain proofs.

[6] 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.

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 $H(t) = \int_0^t h(\tau)d\tau$. 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 $h > 0$, the marginal absorption cost is greater than the average absorption cost, $C' > C/h$. We also assume that there is an upper bound on h, denoted by $\overline{h} > 0$.

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 time horizon T is sufficiently short, such that

$$C'(\overline{h}) - \frac{C(\overline{h})}{\overline{h}} > \frac{T\pi'(0)}{2} \tag{1}$$

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

$$1 + \frac{H\pi''(H)}{\pi'(H)} \geq 0 \tag{2}$$

Remark 1: Assumption A1(a) implies that

$$C''(h) - C'(h)h^{-1} + C(h)h^{-2} > 0 \tag{3}$$

Clearly, the function $C(h) = bh^{\alpha}$ (where $\alpha > 1$ and $b > 0$) 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 A2 ensures that the optimal constant h is strictly smaller than $\overline{h}$.[7] 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

$$V = \int_0^T \left[\pi(H(t)) - C(h(t))\right] dt \tag{4}$$

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

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

[7] As shown in the Appendix, assumption A2 can be replaced by a weaker assumption.

functions (the case where $h(t)$ is not constrained to be piece-wise constant is analysed in a companion paper):[8]

$$h(t) = \begin{cases} h & \text{if } t \in [0, t_S] \\ 0 & \text{if } t \in (t_S, T] \end{cases} \tag{5}$$

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 $H_S \equiv ht_S$.The optimization problem of the joint venture then reduces to that of choosing two numbers h and t_S to maximize

$$V(h, t_S) = \int_0^{t_S} [\pi(ht) - C(h)]\, dt + [T - t_S]\, \pi\,(ht_S) \tag{6}$$

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

Proposition 1: *The solution of the (first-best) optimization problem (6) of the 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 $\overline{h}$.

(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:

$$(T - t_S^*)\pi'(h^* t_S^*) = \frac{C(h^*)}{h^*}. \tag{7}$$

(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:

$$C'(h^*) - \frac{C(h^*)}{h^*} = \frac{1}{t_S^*} \int_0^{t_S^*} \left[\frac{\partial}{\partial h}\pi(h^* t)\right] dt \tag{8}$$

Proof : See Appendix 1.

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

[8] 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.

"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:

$$t^{+}(h) \equiv \min\left\{t_S, \sup_t \{t \in [0,T] : \pi(ht) < C(h)\}\right\} \tag{9}$$

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 (7) and (8) we get:

$$t_S^* = \left(\frac{(\alpha-1)(\gamma+1)}{1+(\alpha-1)(\gamma+1)}\right)T, \qquad h^* = \left(\frac{\alpha K}{c(\alpha-1)(\gamma+1)}\right)^{\frac{1}{\alpha-\gamma}} (t_S^*)^{\frac{\gamma}{\alpha-\gamma}} \tag{10}$$

and

$$t^{+}(h^*) = \min\left\{t_S^*, \left(\frac{\gamma c}{\alpha K}\right)^{\frac{1}{\gamma}} (h^*)^{\frac{\alpha-\gamma}{\gamma}}\right\}. \tag{11}$$

Thus the cumulative transfer is

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

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 (9) (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,

$$V_M \equiv \int_0^{t_B} [\pi(H(t)) - C(h(t)) - w(t)]\, dt + \int_{t_B}^{T} \phi(t)\, dt, \tag{13}$$

and

$$V_L \equiv \int_0^{t_B} w(t)\, dt + \int_{t_B}^{T} [\pi(H(t)) - \phi(t)]\, dt. \tag{14}$$

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

$$0 \leq N_L(t) \equiv \begin{cases} \int_0^t w(\tau)\, d\tau & \text{if } t \in [0, t_B] \\ \int_0^{t_B} w(\tau)\, d\tau + \int_{t_B}^{t} [\pi(H(\tau)) - \phi(\tau)]\, d\tau & \text{if } t \in (t_B, T] \end{cases} \tag{15}$$

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

$$\phi(t) = 0 \text{ for } t \in (t_B, T] \tag{16}$$

The goals of this section are (a) to show that when both constraints (15) and (16) 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 (15), can be simplified to

$$0 \leq \int_0^t w(\tau)\, d\tau \text{ for all } t \in [0, t_B]. \tag{17}$$

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 (17) holds.

Then, the program of the multinational can be written as

$$\max_{h, t_S, w(.)} V_M = \int_0^{t_B} [\pi(H(t)) - C(h(t)) - w(t)]\, dt \tag{18}$$

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

$$t_B = \arg\max_{t \in [0,T]} \left[V_L = \int_0^t w(\tau)\, d\tau + (T - t)\pi(H(t)) \right] \tag{19}$$

and the credit constraint (17).

Here $H(t) = \int_0^t h(\tau)d\tau$, and

$$h(t) = \begin{cases} h & \text{if } t \in [0, \min(t_S, t_B)] \\ 0 & \text{if } t \in (\min(t_S, t_B), T] \end{cases} \tag{20}$$

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

$$V_L^0(h, t_B) = (T - t_B)\pi(H(t_B)) \tag{21}$$

where

$$H(t_B) = \begin{cases} ht_B & \text{if } t_B < t_S \\ ht_S & \text{if } t_B \geq t_S \end{cases} \tag{22}$$

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

$$R(h, t_B) \equiv (T - t_B)\pi(ht_B) \text{ where } t_B \in [0, t_S] \tag{23}$$

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

(i) If

$$(T - t_S)\pi'(ht_S)h - \pi(ht_S) \geq 0 \tag{24}$$

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

$$(T - t_S)\pi'(ht_S)h - \pi(ht_S) < 0 \tag{25}$$

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

$$\underline{V}_L(h) \equiv (T - \widehat{t}_B(h))\pi(h\widehat{t}_B(h)). \tag{26}$$

(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:*

$$(T - \widehat{t}_B(h))\pi'(h\widehat{t}_B(h))h - \pi(h\widehat{t}_B(h)) = 0 \tag{27}$$

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

$$\frac{\partial^2 R(h, t_B)}{(\partial t_B)^2} = (T - t_B)\pi''(ht_B)h^2 - 2\pi'(ht_B)h < 0 \tag{28}$$

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

$$\frac{\partial R(h, t_B)}{\partial t_B} = (T - t_B)\pi'(ht_B)h - \pi(ht_B) \tag{29}$$

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 (26) gives

$$\begin{aligned} \partial \underline{V}_L(h)/\partial h &= \left[T - \widehat{t}_B(h)\right] \pi'(h\widehat{t}_B(h))\widehat{t}_B(h) \\ &\quad + \left\{(T - \widehat{t}_B(h))\pi'(h\widehat{t}_B(h))h - \pi(h\widehat{t}_B(h))\right\} \frac{dt_B}{dh} \end{aligned} \tag{30}$$

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

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

$$\underline{V}_L(h, t_S) \equiv (T - \widehat{t}_B(h, t_S))\pi(h\widehat{t}_B(h, t_S))). \tag{31}$$

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 (25) 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 (24) 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 (25) 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.
$(\widehat{t_B}(h^*) < t_S^*)$
$(T = 30,\ \gamma = 1,\ \alpha = 2,\ c = 1,\ K = 2,\ h = h^* = 20)$.

Using the parameters of example 1c condition (24) 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 $\widehat{t_B}(h^*) = t_S^* = 10$.

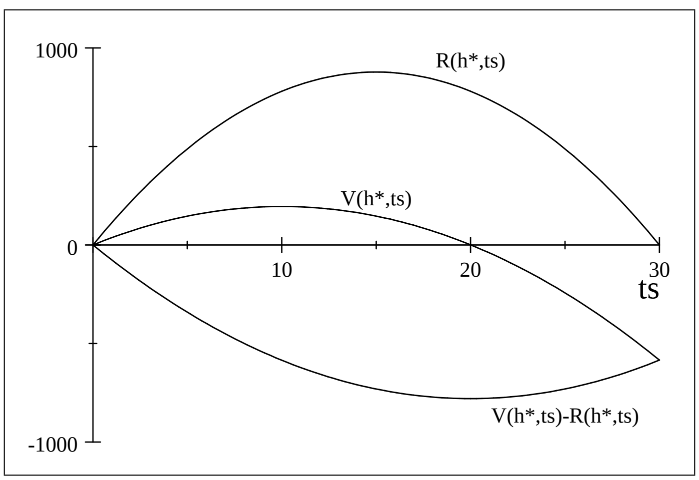

Fig. 2: Case where the local firm breaks away at the first best transfer-stopping time
$(\widehat{t_B}(h^*) = t_S^* = 10)$.
$(T = 30,\ \gamma = 1,\ \alpha = \frac{5}{4},\ c = 1,\ K = 0.1,\ h = h^* \simeq 39)$

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 $\underline{V}_L(h) - (T - t_B^C)\pi(ht_B^C)$. (Here, the superscript c in t_B^C indicates that it is induced by a *contractual* flow of side payments, as will be seen below.)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 4) 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

$$\int_0^{\widehat{t}_B(h)} w^C(t)\,dt = 0 \text{ and } \int_{\widehat{t}_B(h)}^{t_B^C} w^C(t)\,dt + (T - t_B^C)\pi(ht_B^C) = \underline{V}_L(h) \tag{32}$$

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

$$\begin{aligned} F &= [\underline{V}_L(h) - R(h,t_1)] \\ &\quad + [R(h,t_1) - R(h,t_2)] + ... + [R(h,t_{n-1}) - R(h,t_n)] \qquad (33) \\ &\equiv F_1 + F_2 + .. + F_n \qquad (34) \end{aligned}$$

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

$$\widetilde{w}(t_B) = \begin{cases} 0 & \text{if } t_B < t_B^C \\ \underline{V}_L(h) - \left[T - t_B^C\right]\pi(ht_B^C) & \text{if } t_B = t_B^C \end{cases} \qquad (35)$$

Let us now make use of the incentive constraint (35) to determine the multinational's optimal choice of both h and t_B^C to maximize its own payoff:

$$\widetilde{V}_M = \int_0^{t_B^C} [\pi(ht) - C(h)]\,dt + \left[T - t_B^C\right]\pi(ht_B^C) - \underline{V}_L(h) \qquad (36)$$

The first order condition with respect to t_B^C is

$$\frac{\partial \widetilde{V}_M}{\partial t_B^C} = (T - t_B^C)h^C\pi'(h^C t_B^C) - C(h^C) = 0 \qquad (37)$$

This condition has the same form as the first best condition (see equation (7)), except of course the value h is in general not the same. The first order condition with respect to h is

$$\frac{\partial \widetilde{V}_M}{\partial h} = \frac{\partial V}{\partial h} - \frac{\partial \underline{V}_L(h)}{\partial h} = 0 \tag{38}$$

or

$$\int_0^{t_B^C} \left[\tau\pi'(h^C\tau) - C'(h^C)\right] d\tau + (T - t_B^C)\pi'\left(h^C t_B^C\right) t_B^C - \left[T - \widehat{t}_B(h^C)\right] \pi'(h^C \widehat{t}_B(h^C))\widehat{t}_B(h^C) = 0 \tag{39}$$

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

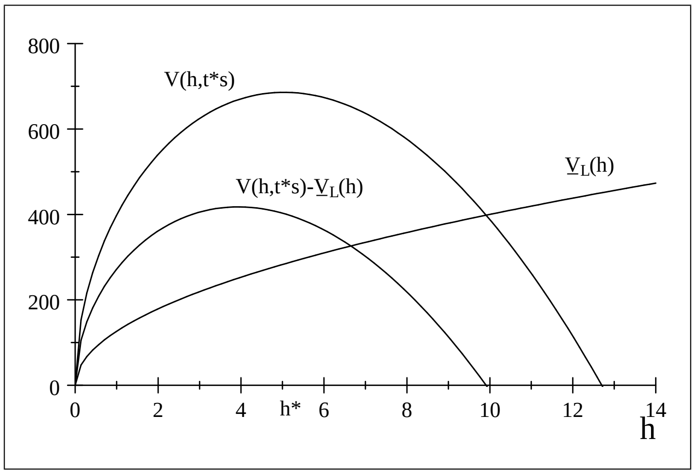

Fig. 3: The secure value of the local firm and the pace of technology transfer.
$(T = 30,\ \gamma = 1,\ \alpha = \frac{1}{2},\ c = 1,\ K = 2,\ t = t_S^* = 18)$

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 $h \simeq 3.93$ 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 i) the multinational will choose a slower transfer rate $h^C < h^*$ and ii) 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 (37) and (39) 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:

$$\frac{\partial V_M}{\partial h} = \int_0^{t_S^*} \left[\tau\pi'(h^*\tau) - C'(h^*)\right] d\tau + (T - t_S^*)\pi'\left(h^* t_S^*\right) t_S^* = 0 \tag{40}$$

$$\frac{\partial V_M}{\partial t_S} = (T - t_S^*)h^*\pi'(ht_S^*) - C(h^*) = 0 \tag{41}$$

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:

$$W_1 \equiv \int_0^t [\tau\pi'(h\tau) - C'(h)]\, d\tau + (T-t)\pi'(ht)\, t \tag{42}$$
$$-\delta\left[T - \widehat{t}_B(h)\right]\pi'(h\widehat{t}_B(h))\widehat{t}_B(h) = 0$$

$$W_2 \equiv (T-t)h\pi'(ht) - C(h) = 0 \tag{43}$$

Clearly, if $\delta = 1$, the system (42)-(43) is equivalent to the system of equations (37)-(39) and thus yield $(h,t) = (h^C, t_B^C)$, and if $\delta = 0$, the system (42)-(43) is equivalent to the system of equations (41)-(40) 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:

$$\begin{bmatrix} W_{11} & W_{12} \\ W_{21} & W_{22} \end{bmatrix} \begin{bmatrix} d\widetilde{h} \\ d\widetilde{t} \end{bmatrix} = \begin{bmatrix} -W_{1\delta} \\ 0 \end{bmatrix} d\delta \tag{44}$$

Then

$$\frac{d\widetilde{h}}{d\delta} = \frac{-W_{1\delta}W_{22}}{W_{11}W_{22} - W_{21}W_{12}} \tag{45}$$

$$\frac{d\widetilde{t}}{d\delta} = \frac{W_{1\delta}W_{21}}{W_{11}W_{22} - W_{21}W_{12}} \tag{46}$$

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 $W_{1\delta} = -\left[T - \widehat{t}_B(h)\right]\pi'(h\widehat{t}_B(h))\widehat{t}_B(h) < 0$, 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 $W_{21} = -C' + (T-t)(ht\pi'' + \pi')$.Using (43),

$$-C' + (T-t)\pi' = -C' + \frac{C(h)}{h} < 0 \tag{47}$$

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.

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

$$\frac{d\widetilde{H}(\delta)}{d\delta} = \frac{d\widetilde{h}(\delta)}{d\delta} \times \widetilde{t}(\delta) + \frac{d\widetilde{t}(\delta)}{d\delta} \times \widetilde{h}(\delta). \tag{48}$$

Using (45) and (46)

$$\frac{d\widetilde{H}}{d\delta} = \frac{-W_{1\delta}}{W_{11}W_{22} - W_{21}W_{12}} \left[\widetilde{t}W_{22} - \widetilde{h}W_{21}\right]. \tag{49}$$

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

$$\widetilde{t}W_{22} - \widetilde{h}W_{21} = \widetilde{H}\left[-\pi' + (T - \widetilde{t})\widetilde{h}\pi''\right] - \widetilde{h}\left[(T - \widetilde{t})\left(\widetilde{H}\pi'' + \pi'\right) - C'\right] \tag{50}$$

Then

$$\widetilde{t}W_{22} - \widetilde{h}W_{21} = \widetilde{h}\left[C' - (T - \widetilde{t})\pi' - \widetilde{t}\pi'\right]. \tag{51}$$

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

$$\frac{1}{\widetilde{t}} \int_0^{\widetilde{t}} \left[\tau\pi'(\widetilde{h}\tau)\right] d\tau \leq \widetilde{t}\pi'(\widetilde{H}). \tag{52}$$

Using (42) we obtain

$$\widetilde{t}\pi'(\widetilde{H}) \geq C'(\widetilde{h}) - (T - \widetilde{t})\pi'\left(\widetilde{H}\right) + \frac{\delta}{\widetilde{t}}\left[T - \widehat{t}_B(\widetilde{h})\right]\pi'(\widetilde{h}\widehat{t}_B(\widetilde{h}))\widehat{t}_B(\widetilde{h}). \tag{53}$$

Then, if $\delta > 0$, $\widetilde{t}\pi'(\widetilde{H}) > C'(\widetilde{h}) - (T - \widetilde{t})\pi'\left(\widetilde{H}\right)$. Using this inequality and (51), we get $\widetilde{t}W_{22} - \widetilde{h}W_{21} < 0$.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.

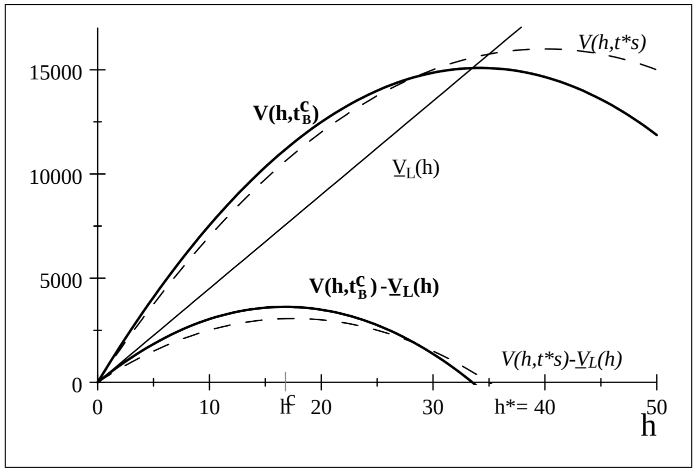

Fig. 4: The secure value of the local firm and the pace of technology transfer.
$(T = 30,\ \gamma = 1,\ \alpha = 2,\ c = 1,\ K = 2)$

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 $t^{+}(h)$,

$$\int_{0}^{t^{+}(h)} [\pi(h^{*}t) - C(h^{*})]\, dt < 0, \tag{54}$$

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 The Effect of a Fall in Transfer Costs on the Intensity of Technology Transfer

In this section, we obtain some comparative static results on parametric changes on the technology-transfer cost function, explain their effects on the duration and the pace of technology transfer. The parametric changes may be interpreted as changes in transfer costs of a given technology, or as a comparison of different transfer costs associated with different technologies. Transfer costs may fall because of an exogenous change in communication technology. Does a fall in transfer costs affect the first-best and second-best intensity of transfer in the same way? In this section, we show how an exogenous fall in transfer costs may impact the intensity of technology transfer, both under the first-best scenario (perfect property rights) and under the second-best scenario. For simplicity, we will assume the profit function is linear, $\pi(H) = KH$, and consider two different interpretations of a "fall in transfer cost". We call these Type I and Type II fall in transfer cost, respectively. In both cases, the upper-bound on feasible transfer rate is denoted by $\overline{h}$.

5.1 Type I fall in transfer costs

Consider the convex transfer cost function $C(h) = b(h/\overline{h})^{\alpha}$ where $\alpha > 1$ and $b > 0$. Then $C(0) = 0$ and $C(\overline{h}) = 1$. An increase in α is called a Type I fall in transfer costs. It has two effects. First, $C(h)$ becomes lower for any $h \in \left(0, \overline{h}\right)$. We call this the "cost-saving effect". Second, when α increases, the marginal cost of transfer becomes lower for small h (near $h = 0$) but it becomes higher for h near the upper-bound $\overline{h}$.[9] We call this the "convexity-

[9] Since $C'(h) = \alpha\overline{h}(h/\overline{h})^{\alpha-1}$ we get

$$\frac{d \ln C'(h)}{d\alpha} = \frac{1}{\alpha} + \ln\left(\frac{h}{\overline{h}}\right)$$

modifying effect". Intuitively, the first effect favors an increase in h, i.e., a speeding-up of technology transfer, and the second effect favors an increase in h if h is small, and a decrease in h if h is large. What is the net effect on h? We can show that the answer depends crucially on the size of two exogenous variables, namely the maximum feasible transfer rate $\overline{h}$, and the length of the time horizon, T. We obtain the following results (the proofs of which are in Appendix 5).

Result A1 (on transfer rate)

In the first-best scenario, a Type I fall in transfer cost (an increase in α) will result in a lengthening of the transfer phase, $[0, t_S^*]$. It will also result in an increase of transfer rate (i.e., an increase in h) in the case where $\overline{h}$ or T are small enough so that $\overline{h}T \leq b/K$). However, in the case where $\overline{h}T > b/K$, an increase in α will result in an increase in h only if the existing α is greater than a threshold level $\widetilde{\alpha}$; if $\alpha < \widetilde{\alpha}$, a small increase in α will result in a decrease in h.[10]

The intuition behind Result 1 is as follows. If $\overline{h}T$ is small, then the optimal h^* is small, therefore the "convexity-modifying effect" works in the same direction as the "cost saving" effect. If $\overline{h}T$ is large, then the optimal h^* is large, therefore "convexity-modifying effect" and "cost saving" effect work in opposite directions. The cost saving effect is stronger only if α is large enough.

Result A2 (on first-best accumulated transfer)

The effect of a Type I fall in transfer cost on total transfer, $h^* t_S^*$, depends on the size of the maximum feasible accumulated transfer $\overline{h}T$. If $\overline{h}T \leq b/K$, then $h^* t_S^*$ will increase with α. If $\overline{h}T > b/K$, an increase in α will lead to an increase in $h^* t_S^*$ only if the existing α is greater than a threshold level $\widehat{\alpha} < \widetilde{\alpha}$; if $\alpha < \widehat{\alpha}$, a small increase in α will lead to a decrease in $h^* t_S^*$.

For $\alpha > \widetilde{\alpha}$, an increase in α increases both h^* and t_S^* (from Result A1 above) so clearly $h^* t_S^*$ increases. Given $\overline{h}T > b/K$, if $\alpha \in (\widehat{\alpha}, \widetilde{\alpha})$ the t_S^*-lengthening effect of a small increase in α outweighs the h^*-decreasing effect of a small increase in α, therefore $h^* t_S^*$ increases, while if $\alpha < \widehat{\alpha}$ the latter effects dominates, so $h^* t_S^*$ decreases.

Result A3 (on the second-best case)[11]

(i) *In the second-best scenario, a Type I fall in transfer cost (i.e., an increase in α) will increase the "contractual" breakup time t_B^C.*

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is positive for h near $\overline{h}$ and negative for h near zero.

[10] The threshold level is dependent (in fact increasing) in $\overline{h}T$. Note also that we assume an interior solution, $h^* < \overline{h}$, for which it is necessary and sufficient that $2\alpha - 1 > \overline{h}TK/b$.

[11] We restrict attention to interior second-best solutions, $h^C < \overline{h}$. A sufficient condition for this is $\overline{h}TK/b < 2\alpha - 1$.

(ii) *The ratio* t_B^C/t_S^* *is greater than unity; it decreases if* α *increases.*

(iii) *The ratio* h^C/h^* *is smaller than unity; it increases if* α *increases.*

(iv) *If* $\overline{h}T \leq b/K$*, then,* h^C *increases with* α*.*

(v) *If* $\overline{h}T > b/K$, *there exists* $\widetilde{\alpha}_c > 1$ *such that* h^C *increases with* α *for* $\alpha \geq \widetilde{\alpha}_c$*.*

(vi) *If* $\overline{h}T > \frac{1}{2-\sqrt{2}}b/K$, *there exists* $\underline{\alpha}$ *such that* h^C *decreases with* α *for* $\alpha \in (1, \underline{\alpha})$ *and increases with* α *for* $\alpha > \underline{\alpha}$*.*

5.2 Type II fall in transfer costs

In the example considered above, it was assumed that $C(h) = b(h/\overline{h})^{\alpha}$ where $\alpha > 1$ and $b > 0$. Clearly a decrease in b also represents a fall (but of a different type) in transfer costs. When b decreases, this reduces transfer cost at any given h, and unambiguously reduces the marginal cost of transfer, regardless of whether h is near zero or near $\overline{h}$.

When b decreases, there are two effects on the cost function. First, for h given, the cost of transfer decreases. This effect tends to favor an increase in h. Second, the cost curve becomes less convex, as marginal cost falls. This is the "convexity or curvature" effect. This convexity effect favors an increase in h. In contrast to the previous example where there were two effects that could go in opposite directions, here the two effects are going in the same direction. This explains why our results (presented below) for a Type II fall in transfer costs are not ambiguous. We obtain the following result (see Appendix 5).

Result B: *In both the first-best and second-best scenarios, a Type II fall in transfer costs (a decrease in b) will not affect the duration of the transfer (*t_S^* and t_B^C*). It results in an increase of transfer rate (i.e., an increase in* h^* and h^C*) and an increase of the amount of technology transferred (*$h^*t_S^*$ and $h^C t_B^C$*).*

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, with special emphasis on the time-compression costs of technology transfer. We have shown that when the host country cannot enforce joint venture contract, the multinational will have an incentive to reduce both the pace of technology transfer and the cumulative amount of technology transfer even if the duration of the transfer is longer. In other words, transfer is both reduced and delayed. The sign of the comparative statics of a "fall in technology-transfer costs" on the pace of transfer (both in the first-best and second-best scenarios) is shown to depend on the life-span of the product, T, and the maximum feasible speed of transfer, $\overline{h}$.

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 and delay the 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.

While the motive of our study is to shed light on technology transfer in a joint-venture, clearly our model can be applied to other situations involving 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.

Appendices

Appendix 1: Proof of Proposition 1

The choice set Ω defined by $\Omega = \left\{(h, t_S) : 0 \leq h \leq \overline{h} \text{ and } 0 \leq t_S \leq T\right\}$ is a compact set. The objective function (6) 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 $h = \overline{h}$. To take into account the constraints $T - t_S \geq 0$ and $\overline{h} - h \geq 0$, we introduce the associated Lagrange multipliers $\lambda \geq 0$ and $\mu \geq 0$. The Lagrangian is

$$L = \int_0^{t_S} [\pi(ht) - C(h)]\, dt + (T - t_S)\pi\,(ht_S) + \lambda(T - t_S) + \mu(\overline{h} - h) \tag{A.1}$$

The first order conditions are

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

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

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

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

To show that $h^* < \overline{h}$, let us suppose that $h^* = \overline{h}$. Then, using (A.4), and $h^* = \overline{h}$, condition (A.3) gives

$$\begin{aligned} C'(\overline{h})t_S^* - \frac{C(\overline{h})}{h^*}t_S^* &\leq C'(\overline{h})t_S^* - \frac{C(\overline{h})}{\overline{h}}t_S^* + \mu \\ = \int_0^{t_S} t\pi'(\overline{h}t)dt &\leq \pi'(0)\int_0^{t_S} tdt = \frac{\pi'(0)(t_S^*)^2}{2} \end{aligned} \tag{A.5}$$

which violates assumption A2.[12] Thus $h^* < \overline{h}$. This concludes the proof that (h^*, t_S^*) is in the interior of Ω.

It follows that

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

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

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

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

The SOCs are

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

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

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

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

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

[12] Note that we can replace assumption A2 by the following. Assumption A2':

$$C'(\overline{h}) - \frac{C(\overline{h})}{h^*} > \frac{\pi'(0)t_S^*}{2}$$

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

(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 $V_{11}V_{22}>(V_{12})^2$.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,

$$(V_{12})^2=[(T-t_S)\pi''(ht_S)\,ht_S]^2+\left[\frac{C(h)}{h}-C'(h)\right]^2+2(T-t_S)\pi''(ht_S)\,ht_S\left[\frac{C(h)}{h}-C'(h)\right] \tag{A.19}$$

Secondly,

$$V_{11}V_{22}\;>\;\left\{(T-t_S)\pi''(ht_S)(h)^2-\pi'(ht_S)\,h\right\} \tag{A.20}$$

$$\times\left\{(T-t_S)\pi''(ht_S)(t_S)^2-C''(h)t_S\right\} \tag{A.21}$$

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

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

Hence

$$\Delta \geq -(T-t_S)\,\pi''(ht_S)\,ht_S\left[\pi'(ht_S)\,t_S + hC''(h) - 2\left(C'(h) - \frac{C(h)}{h}\right)\right] \tag{A.22}$$

$$+C''(h)\pi'(ht_S)\,ht_S - \left[\frac{C(h)}{h} - C'(h)\right]^2 \tag{A.23}$$

Using the implication of assumption A1 stated in (3), which can be written as $hC''(h) > \left(C'(h) - \frac{C(h)}{h}\right)$, we have

$$\Delta \;>\; \left[\left(C'(h) - \frac{C(h)}{h}\right) - (T-t_S)\,\pi''(ht_S)\,ht_S\right] \tag{A.24}$$

$$\times\left[\pi'(ht_S)\,t_S - \left(C'(h) - \frac{C(h)}{h}\right)\right]. \tag{A.25}$$

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

$$\left[C'(h^*) - \frac{C(h^*)}{h^*}\right] t_S^* = \int_0^{t_S} \left[t\pi'(h^*t)\right] dt. \tag{A.26}$$

If A3 holds, $t\pi'(h^*t)$ is increasing in t (remark 1). Then $\pi'(ht_S)\,t_S \geqslant \int_0^{t_S}\left[t\pi'(h^*t)\right] dt$ .We conclude that $\Delta > 0$.

Appendix 2: The local firm's optimal breakaway time

Consider the isoelastic profit function $\pi(H) = (1/\gamma)H^\gamma$ where $0 < \gamma < 1$. Then equation (27) gives a unique $\widehat{t}_B(h)$ that is independent of h :

$$(T - t_B)H^{\gamma-1}h = \frac{1}{\gamma}H^\gamma \tag{A.27}$$

so

$$H^\gamma\left[\frac{T}{t_B} - \frac{1+\gamma}{\gamma}\right] = 0 \tag{A.28}$$

Thus

$$\widehat{t}_B = \frac{\gamma}{1+\gamma}T. \tag{A.29}$$

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

The first order condition ((37) and (39))of the program can be rewritten as

$$K(T-t_B^C)h - C(h) = 0, \tag{A.30}$$

$$K\frac{\left(t_B^C\right)^2}{2} - t_B^C C'(h) + K(T-t_B^C)t_B^C - K\frac{T^2}{4} = 0. \tag{A.31}$$

Equivalently,

$$K(T-t_B^C)h - C(h) = 0, \tag{A.32}$$

$$K\frac{\left(t_B^C\right)^2}{2} + t_B^C\left[\frac{C(h)}{h} - C'(h)\right] - K\frac{T^2}{4} = 0. \tag{A.33}$$

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

$$\left[K(T-t_B^C) - \frac{c}{\alpha}h^{\alpha-1}\right]h = 0, \tag{A.34}$$

$$K\frac{\left(t_B^C\right)^2}{2} - ct_B^C\left[1-\frac{1}{\alpha}\right]h^{\alpha-1} - K\frac{T^2}{4} = 0. \tag{A.35}$$

If $h > 0$

$$\alpha K(T-t_B^C) = ch^{\alpha-1}, \tag{A.36}$$

$$K\frac{\left(t_B^C\right)^2}{2} - ct_B^C\left[1-\frac{1}{\alpha}\right]h^{\alpha-1} - K\frac{T^2}{4} = 0. \tag{A.37}$$

Or,

$$\alpha K(T-t_B^C) = ch^{\alpha-1}, \tag{A.38}$$

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

The solution is:

$$t_B^C = \frac{\alpha-1+\sqrt{(\alpha-1)^2+\alpha-1/2}}{2\alpha-1}T, \tag{A.40}$$

$$\alpha K(T-t_B^C) = c\left(h^C\right)^{\alpha-1}. \tag{A.41}$$

The contractual breakaway time is

$$t_B^C = \frac{\alpha-1+\sqrt{(\alpha-1)^2+(\alpha-0.5)}}{2\alpha-1}T > t_S^* = \frac{2(\alpha-1)}{2\alpha-1}T \tag{A.42}$$

This implies that

$$\frac{T-t_B^C}{T} = \frac{\alpha-\sqrt{(\alpha-1)^2+(\alpha-0.5)}}{2\alpha-1} \equiv \frac{\mu}{2\alpha-1} > 0 \tag{A.43}$$

where $\mu > 0$ and

$$\mu - 1 < 0 \tag{A.44}$$

The transfer rate is

$$h^C = \left[\frac{\alpha K(T - t_B^C)}{c}\right]^{1/(\alpha-1)} = \left[\frac{\alpha K \mu T}{(2\alpha - 1)c}\right]^{1/(\alpha-1)} < h^* \tag{A.45}$$

because $\mu < 1$.

The optimal lump sum F is

$$F^{**} = \underline{V}_L(h) - \left[T - t_B^C\right]\pi(h^C t_B^C) = \tag{A.46}$$

$$\left[T - \widehat{t}_B(h^C)\right]\pi(h^C \widehat{t}_B(h^C)) - \left[T - t_B^C\right]\pi(h^C t_B^C) \tag{A.47}$$

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

$$(T - t_B^C)h^C - t_B^C h^C < 0 \tag{A.48}$$

i.e.

$$T < 2t_B^C \tag{A.49}$$

This condition is satisfied, because, from (A.42)

$$\frac{t_B^C}{T} = \frac{\alpha - 1 + \sqrt{(\alpha-1)^2 + (\alpha - 0.5)}}{2\alpha - 1} > \frac{1}{2} \tag{A.50}$$

where the strict inequality follows from

$$2\sqrt{(\alpha-1)^2 + (\alpha - 0.5)} > 1 \tag{A.51}$$

i.e.

$$4\left[(\alpha-1)^2 + (\alpha - 0.5)\right] > 1 \tag{A.52}$$

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

Appendix 4: Properties of side transfer schemes

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:

$$\min_{w(.)} \left[\int_0^{t_B^C} w(t)\, dt \right] \tag{A.53}$$

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

$$t_B^C = \arg\max_{t_B} \left[V_L = \int_0^{t_B} w(t)\, dt + (T - t_B)\pi(H(t_B)) \right] \tag{A.54}$$

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

$$0 \leq \int_0^t w(\tau)\, d\tau \text{ if } t \in \left[0, t_B^C\right]. \tag{A.55}$$

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" $\widehat{t}_B(h)$:

$$\int_0^{\widehat{t}_B(h)} w^C(t)\, dt = 0, \tag{A.56}$$

(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 $\underline{V}_L(h)$:

$$\int_0^{t_B^C} w^C(t)\, dt + (T - t_B^C)\pi(ht_B^C) = (T - \widehat{t}_B(h))\pi(h\widehat{t}_B(h)) \equiv \underline{V}_L(h) \tag{A.57}$$

(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 $\underline{V}_L(h)$:

$$0 \leq \int_{\widehat{t}_B(h)}^t w^C(\tau)\, d\tau \leq (T - \widehat{t}_B(h))\pi(h\widehat{t}_B(h)) - (T - t_B)\pi(ht_B) \tag{A.58}$$

Proof:

(i) Proof of sufficiency: It is easy to verify that when $w^C(.)$ satisfies conditions (A.56), (A.57) and (A.58) it is a solution of (A.53).

(ii) Proof of necessity: Consider a solution of (A.53). We show that it must satisfy conditions (A.56), (A.57) and (A.58).

To show the necessity of condition (A.57), suppose that $w^C(.)$ does not satisfy condition (A.57). If the left-hand side of (A.57) is strictly smaller than $\underline{V}_L(h)$, the local would not choose t_B^C and hence the incentive constraint (A.54) is violated. If the left-hand side of (A.57) 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.58). If $w^C(.)$ does not satisfy the left inequality of condition (A.58) then condition (A.55) is not satisfied. If $w^C(.)$ does not satisfy the right inequality part of condition (A.58), then there exists $\widetilde{t}_B$ within the interval $\left[\widehat{t}_B(h), t_B^C\right]$ such that

$$\int_{\widehat{t}_B(h)}^{\widetilde{t}_B} w^C(t)\,dt > (T-\widehat{t}_B(h))\pi(h\widehat{t}_B(h)) - (T-\widetilde{t}_B)\pi(h\widetilde{t}_B) \tag{A.59}$$

From the incentive constraint (A.54), 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.

$$\int_{\widetilde{t}_B}^{t_B^C} w^C(t)\,dt \geq (T-\widetilde{t}_B)\pi(h\widetilde{t}_B) - (T-t_B^C)\pi(H(t_B^C)) \tag{A.60}$$

Adding inequalities (A.59) and (A.60) we have

$$\int_0^{t_B^C} w^C(t)\,dt + (T-t_B^C)\pi(H(t_B^C)) > \int_0^{\widehat{t}_B(h)} w^C(t)\,dt + (T-\widehat{t}_B(h))\pi(h\widehat{t}_B(h)) \tag{A.61}$$

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.56). Suppose that $w^C(.)$ does not satisfy condition (A.56), i.e.

$$\int_0^{\widehat{t}_B(h)} w^C(t)\,dt > 0, \tag{A.62}$$

Using the incentive constraint (A.54), we obtain

$$\begin{aligned}\int_0^{t_B^C} w^C(t)\,dt + (T-t_B^C)\pi(H(t_B^C)) &\geq \int_0^{\widehat{t}_B(h)} w^C(t)\,dt + (T-\widehat{t}_B(h))\pi(h\widehat{t}_B(h)) \\ &> (T-\widehat{t}_B(h))\pi(h\widehat{t}_B(h))\end{aligned} \tag{A.63}$$

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

Appendix 5: Effects of reduced transfer cost on first-best and second-best transfer schemes

Proof of Results A1-A2: For the cost function $C(h) = b(h/\overline{h})^\alpha$ where $\alpha > 1$ and $b > 0$, consider an increase in α. The first-best FOCs give $(K/b)(T-t_S^*) = h^{\alpha-1}/(\overline{h})^\alpha$ and $(T-t_S^*)(\alpha-1) = t_S^*/2$. Hence

$$0 < t_S^* = \left(1 - \frac{1}{2\alpha - 1}\right) T$$

If $\overline{h}TK/b < 2\alpha - 1$ (condition for an interior solution), the optimal quantity of knowledge transferred at $t \le t_S^*$ is

$$h^*(\alpha) = \overline{h}\left[\frac{\overline{h}TK/b}{2\alpha - 1}\right]^{\frac{1}{\alpha-1}} < \overline{h}$$

Then

$$\ln(h^*/\overline{h}) = \frac{1}{\alpha - 1}\ln\left(\frac{1}{2\alpha - 1}\right) + \frac{1}{\alpha - 1}\ln\left(\overline{h}TK/b\right) \tag{A.64}$$

The first term on the RHS of (A.64) is increasing in α :

$$\frac{d}{d\alpha}\left[\frac{-1}{\alpha - 1}\ln\left(2\alpha - 1\right)\right] = \frac{1}{\left(\alpha - 1\right)^2}\left[\ln(2\alpha - 1) - 1 + \frac{1}{(2\alpha - 1)}\right] > 0$$

because $\ln x - 1 + (1/x) > 0$ for all positive $x \neq 1$.(Recall: let $f(x)$ be a strictly concave function, $f(x) - f(q) > f'(x)(x - q)$ for $x \neq q$; take $f(x) = \ln x$ and consider $x \neq q = 1$, then, applying the above inequality we get $\ln x \geq \frac{1}{x}(x - 1) = 1 - \frac{1}{x}$). The second term on the RHS of (A.64) is increasing in α if and only if $\ln\left(\overline{h}TK/b\right) < 0$. So the RHS of (A.64) is increasing in α if $\overline{h}TK/b < 1$. If $\overline{h}TK/b > 1$ then

$$\frac{d}{d\alpha}\ln(h^*/\overline{h}) = \frac{1}{\left(\alpha - 1\right)^2}\left[\ln(2\alpha - 1) - 1 + \frac{1}{(2\alpha - 1)} - \ln\left(\overline{h}TK/b\right)\right]$$

which is equal to zero at a unique α, say $\widetilde{\alpha} > 1$.

By a similar argument, if $\overline{h}TK/b \leq 1$, then the total cumulative technology transfer $H^*(\alpha) = h^*(\alpha)t_S^*(\alpha)$ increases with α; while if $\overline{h}TK/b > 1$, there exists $\widehat{\alpha} > 1$ such that $H^*(\alpha)$ decreases with α for $1 \leq \alpha \leq \widehat{\alpha}$, and $H^*(\alpha)$ increases with α for $\alpha \geq \widehat{\alpha}$.

Proof of Results A3:

The FOCs for the second best situation are

$$\int_0^t \left[\tau\pi'(h\tau) - C'(h)\right] d\tau + (T - t)\pi'\left(ht\right)t \tag{A.65}$$

$$- \left[T - \widehat{t}_B(h)\right]\pi'(h\widehat{t}_B(h))\widehat{t}_B(h) = 0$$

$$(T - t)h\pi'(ht) - C(h) = 0 \tag{A.66}$$

Where $\widehat{t}_B(h) = Min\left(\underset{t_B\in[0,T]}{\arg\max}\left[(T - t_B)\pi(ht_B)\right], t_B^C\right)$. Here, $\underset{t_B\in[0,T]}{\arg\max}\left[(T - t_B)\pi(ht_B)\right] = \frac{T}{2}$. Suppose for the moment that $t_B^C \geq \frac{T}{2}$ (we will later verify that this holds at the second-best optimum). Then the FOCs can be rewritten as

$$K\frac{t^2}{2} - \alpha b\frac{h^{\alpha-1}}{\left(\overline{h}\right)^{\alpha}}t + K(T - t)t - \frac{KT^2}{4} = 0 \tag{A.67}$$

$$K(T-t)h - b\left(\frac{h}{\overline{h}}\right)^{\alpha} = 0 \tag{A.68}$$

Remark that in this case, the only difference with the first best case is the constant term $-\frac{(KT)^2}{4}$, hence the second order conditions are also satisfied.

We can compute the second best duration and pace of technology transfer:

$$\begin{aligned} t_B^C(\alpha) &= \frac{\alpha - 1 + \sqrt{(\alpha-1)^2 + \alpha - \frac{1}{2}}}{2\alpha - 1} T \\ &> \frac{\alpha - 1 + \sqrt{(\alpha-1)^2 + \alpha - \frac{1}{2}}}{2\alpha - 2} T > \frac{T}{2} \end{aligned}$$

Define, for $\alpha \geq 1$,

$$D(\alpha) \equiv \alpha - \sqrt{(\alpha-1)^2 + \alpha - \frac{1}{2}} < 1$$

The second-best rate of transfer is

$$h^C(\alpha) = \left(\frac{D(\alpha)}{2\alpha - 1}\overline{h}T\frac{K}{b}\right)^{\frac{1}{\alpha-1}} \overline{h}$$

which is less than $\overline{h}$, given that $\overline{h}T\frac{K}{b} < 2\alpha - 1$.

$$\frac{\partial t_B^C}{\partial \alpha}(\alpha) = \frac{1}{(2\alpha-1)^2}\left[2\sqrt{(\alpha-1)^2 + \alpha - \frac{1}{2}} - 1\right] > 0$$

because $2\sqrt{(\alpha-1)^2 + \alpha - \frac{1}{2}} - 1 > 0$ for all $\alpha > 1$. The ratio $t_B^C(\alpha)/t_S^*(\alpha)$ decreases with α.

Let $\varphi(\alpha) \equiv \ln\left(\frac{h^C(\alpha)}{h^*(\alpha)}\right)$. Its derivative is

$$\begin{aligned} \varphi'(\alpha) &= -\frac{1}{(\alpha-1)^2}\ln(D(\alpha)) \\ &\quad + \frac{1}{(\alpha-1)D(\alpha)}\left[1 - \frac{2\alpha - 1}{2\sqrt{(\alpha-1)^2 + \alpha - \frac{1}{2}}}\right] \end{aligned}$$

The first term is positive and the second term is also positive. So $\varphi'(\alpha) > 0$.

Because the ratio $\frac{h^C(\alpha)}{h^*(\alpha)}$ is increasing in α, it follows that when $h^*(\alpha)$ is increasing in α, $h^C(\alpha)$ must be increasing in α at a faster rate. Now, for $\overline{h}T\frac{K}{b} \leq 1$, we conclude that $h^C(\alpha)$ increases with α. For $\overline{h}T\frac{K}{b} > 1$, then for $\alpha \geq \widetilde{\alpha}$, where $\widetilde{\alpha}$ is the threshold beyond which $h^*(\alpha)$ increases with α, $h^C(\alpha)$ must be increasing in α. But clearly, by continuity, $h^C(\alpha)$ must also be increasing in α for all α belonging to some range $(\underline{\alpha}, \widetilde{\alpha})$ where1 $< \underline{\alpha} < \widetilde{\alpha}$, and

$h^C(\alpha)$ is decreasing in α for all $\alpha \in (1, \underline{\alpha})$. Let us show the existence of this threshold $\underline{\alpha}$. For this purpose, let us define

$$\widehat{h}(\alpha) \equiv \left(\frac{2-\sqrt{2}}{2\alpha - 1} \overline{h} T \frac{K}{b} \right)^{\frac{1}{\alpha-1}} \overline{h}$$

We can show that if $\overline{h}TK/b > \frac{1}{2-\sqrt{2}}$, there exists $\widetilde{\widetilde{\alpha}} > 1$ (where $\widetilde{\widetilde{\alpha}} < \widetilde{\alpha}$) such that $\widehat{h}(\alpha)$ decreases with α for $1 \leq \alpha \leq \widetilde{\widetilde{\alpha}}$, and $\widehat{h}(\alpha)$ increases with α for $\alpha \geq \widetilde{\widetilde{\alpha}}$. Now define

$$\gamma(\alpha) \equiv \ln \left(\frac{h^C(\alpha)}{\widehat{h}(\alpha)} \right) = \frac{1}{\alpha - 1} \ln \left(\frac{D(\alpha)}{2-\sqrt{2}} \right)$$

Then $\gamma'(\alpha) < 0$ for all $\alpha > 1$. So when $\widehat{h}(\alpha)$ is decreasing, $h^C(\alpha)$ must be decreasing at a faster rate. And when $\widehat{h}(\alpha)$ is increasing, $h^C(\alpha)$ may be decreasing (at a slower rate) or increasing. It follows that there exists a threshold $\underline{\alpha} \in \left(\widetilde{\widetilde{\alpha}}, \widetilde{\alpha}\right)$ such that $h^C(\alpha)$ is decreasing if and only if $\alpha < \underline{\alpha}$.

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