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JEL Classification: O3, L1, L22, D23

Keywords: Technology Transfer, vertical contracts, hold-up

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On the Dynamics of Technology Transfer*

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July 19, 2021

Abstract

We study the strategic timing and pace of cost reducing technology transfer by an upstream monopolist to a downstream market when there is potential competition downstream and the protection of intellectual property rights is imperfect. The possibility that the downstream firm may not fully compensate the upstream firm for the benefits that it has received, creates "hold-up" issues. In equilibrium transfer occurs to the same downstream firm in both periods, however the contractual relationship is crucially affected by the presence of competitors - in particular, there is a delay in technology transfer, relative to the vertical integration benchmark. The upstream firm is trying to limit the downstream firm's bargaining power, in an effort to pay lower rent or no rent in the subsequent period. Price competition downstream does not fully eliminate the opportunistic behavior created by the imperfect intellectual property rights.

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1 Introduction

Our study sheds light to aspects of the market structure and the strategic interaction between firms when technology transfer occurs from upstream to downstream firms. While technology transfer in a static model has been studied in the literature, little attention has been given to the pace and the total level of the technology transfer in a dynamic environment. The objective of this paper is to study the strategic timing of the technology transfer when the protection of intellectual property rights is imperfect. The possibility that the downstream firm may not fully compensate the upstream firm for the benefits that it has received creates hold-up issues. We examine whether competition at the downstream level would resolve this hold-up problem.

A common case of technology transfer is when a Multinational Enterprise (MNE) enters a local market in a less developed country and licenses superior technology to one or more local firms, while the contracts that are signed, often due to weak institutions in the less developed country, are not fully enforceable. The vertical chains that are created in this way could be also viewed as joint ventures. A notable example is the joint venture started in 1996 between Danone, one of the world's largest food conglomerates, and the Hangzhou Wahaha Group, the largest beverage producer in China.[1] Danone's goal was to profit from the growing Chinese market and Wahaha's goal was to learn and, thus, profit from Danone's superior technology. In the beginning this partnership was very successful, nevertheless, as the businesses expanded and became more complex, problems also began. "The companies have been battling in dozens of legal jurisdictions since April 2007 after Danone accused Wahaha and Zong Qinghou, the Chinese company's founder, of setting up lucrative parallel businesses." In addition, "[I]n 2007, Danone pulled out of a new dairy venture [...] to concentrate on expanding its own operations in China." (Financial Times, September 2009).[2] Thus, one could say that, apart from the regulatory or institutional challenges, another major reason for the joint venture breakdown was the conflict of interests among the two companies. After Wahaha absorbed the necessary technology it aimed in making its own business outside the joint venture, while Danone wanted to expand its own operations in the foreign country.

A case in which the firm with the superior technology was reluctant to fully transfer technology to its partner is that of the joint venture formed in 1984 between Hero of India and Honda of Japan with the latter to transfer technology on bikes for almost 26 years to the former company. In

[1] See also subsection 2.2 in Garicano and Rayo (2017).

[2] "Danone to quit joint venture with Wahaha", 30 September 2019, FT.

2010, the board of directors of the Hero Honda Group decided to terminate their partnership in a phased manner. "The rising differences between the two partners gradually emerged as an irritant. Differences had been brewing for a few years before the split over a variety of issues, ranging from Honda's reluctance to fully and freely share technology with Hero (despite a 10-year technology tie-up that expired in 2014) as well as Indian partner's uneasiness over high royalty payouts to the Japanese company."[3] These examples illustrate the delays in the technology transfer, as well as the possibility to breakdown a long-term partnership when contract enforcement is imperfect.

In our model we consider a firm, say U, that owns some superior technology but which, for a variety of reasons (variable costs disadvantages, institutional or location restrictions), cannot reach the final consumers in some new/foreign market, unless it contracts with some local (downstream) firm D or several firms (D, D', ...). Such an arrangement makes firm U an "upstream firm". Assume that technology transfer from the upstream to a downstream firm reduces the final's good production cost and cannot be instantaneous, but is gradual. This can be, for example, due to informational or institutional reasons; technology may be embodied in new capital equipment that is costly to purchase, or in managerial decisions or in new labor, or simply there may be absorption costs by the downstream firm. Technically this implies that the technology transfer follows a cost function that is convex in each period. Finally and crucially, assume that technology can only be partly protected by intellectual property laws; exactly, because of informational and institutional reasons like the ones mentioned just above regarding the nature of this transfer or simply because in the foreign market legal enforcement conditions are imperfect. Therefore, unlike standard vertical contracting models on the trade of products, D may stop dealing with U at some point in time and can still continue producing in the future a competing product, even though U may have switched at that point in time to transferring technology to another downstream firm D'. Thus, opportunistic behavior (hold-up issues) becomes very important.

The downstream market structure is endogenized. Will there be just one local downstream firm in equilibrium being supplied by U, as technology efficiency may dictate, or more than one, given the opportunistic behavior? What is the equilibrium pace and the total level of technology transfer under imperfect property rights? How does it compare to the social optimum? Will the downstream firms be able to extract rents due to the threat of stopping dealing with U? Thus, our paper has some interesting features present in three important literatures: technology licensing, the dynamics of Foreign Direct Investment (FDI) and vertical contracting. Nevertheless, the literature has not

[3] From Wikipedia, "Hero MotoCorp".

dealt, to the best of our knowledge, with the general issue of modeling and analyzing situations where the downstream oligopoly market structure, the pace and level of technology transfer and the contractual arrangements are all jointly endogenous in the problem. There are several papers that belong to this general field, but these that study the strategic timing of technology transfer are scarce. One of the key novel elements of our model is that a former licensee competes in the final good market with the subsequent licensees, becoming a formidable competitor due to the technology that it had accumulated while dealing with the upstream firm. This creates a strong strategic link between past and future choices of both upstream and downstream firms. There is a substantial strategic element in the decision about how many licensees to use, how much technology to transfer to each of them, and when exactly.

In the Bertrand competition framework with homogenous good and two-periods, we find that in equilibrium, there is an exclusive contractual relation between U and a single downstream firm D in both periods. Unless all technology is transferred in the first period, there is a delay in technology transfer, comparing to the vertical integration case (VI), that is, the technology transfer in the first period is less than in the case of VI. This delay is due to the fact that U is trying to limit D's bargaining power, in an effort to pay less or no rent in the subsequent period. Additionally, the total level of technology transfer of both periods is never higher than in the VI case (underinvestment or hold-up). Unless the production cost is reduced to zero in the second period, the total level of the technology transferred is less than in the VI case where the upstream firm is locked with its own downstream firm each period. We find that, for some parameter values, D extracts a rent in the second period of the game, due to the bargaining power acquired by the technology transferred in the first period. Firm D has always a cost advantage in the second period compared to the other downstream firms. However, for other parameter values, U manages to avoid paying a rent to D by reducing the technology transfer in the first period to the level that does not make D strong enough to threaten stop dealing with U in the future. In particular, we find that U tends to give rent to D for low values of the discount factor, since future is not valuable enough. Moreover, D tends to extract rent for high values of the technology adoption cost parameter, since U is not willing to reduce the first period's technology transfer to make D extract zero rent, as it is very costly to make up for this underinvestment in the second period. Overall, competition at the downstream level is not able to fully resolve the hold-up problem created by the imperfect intellectual property rights. Finally, when we extend the model to introduce uncertainty in the initial production costs of each downstream firm across periods, we find that for some values of the parameters, U prefers to be vertically separated rather than vertically integrated to avoid sticking with the same downstream partner forever.

Our work is related to three broad literatures: on technology licensing[4], on FDI[5] and on vertical contracting[6]. As each of these literatures is too large to survey here, we only discuss work that is more closely related to the specific setting of our model. There are few papers examining the strategic timing of licensing. There is some work centred on involuntary knowledge transfer (spillovers to competitors). For example, Lin and Saggi (1999) propose a dynamic model where

[4] There are several papers concerning the licensing of technology under imperfect intellectual property rights. Ethier and Markusen (1996) explore a model where alternative modes of serving the foreign market, such as exporting or licensing, emerge endogenously. Another paper by Markusen (2001) presents a model where the moral-hazard problem is double-sided, and finds that contract enforceability constraint on MNE allows it to credibly offer a lower licensing fee. Other relevant papers consider licensing and joint ventures without introducing the assumption of imperfect intellectual property rights. For example, Horstmann and Markusen (1996) introduce a model, where a MNE that is uncertain about the characteristics of demand must decide whether to invest and enter the market directly or to contract a local agent first. Mattoo et al. (2004) examine how the choice between direct entry or acquisition of a domestic firm affects the level of technology transfer. The role of the host country policies on the technology transfer when there is the fear of spillovers is analyzed by Mőller and Schnitzer (2006). Our model explores the hold-up problem and how it is affected by the mode of competition downstream. Felli and Roberts (2000) analyze extensively the idea that competition might resolve the hold-up problem. However in our setting which starts from a perfectly competitive downstream market, the hold-up problem is found to persist as a strategic threat, but is avoided in the equilibrium either by adjusting the amount of technology transfer or by paying a rent. This is due to the fact that in our model the downstream mode of competition is endogenous, since it can be affected by U firm's decisions and thus can be changed strategically.

[5] The role of FDI in international technology transfer has been studied by Saggi (2002) and by Glass and Saggi (2008). The MNE may pay a wage premium to prevent local firms from hiring its workers and thus gaining access to their knowledge in Glass and Saggi (2002a). Technological spillovers from FDI to local firms through worker's mobility also arise in Fosfuri, Motta and Ronde (2001). Additionally, Glass and Saggi (2002b) develop a product cycle model with endogenous innovation, imitation and FDI and Nocke and Yeaple (2007) develop a general equilibrium model with heterogeneous firms to study alternative modes of foreign market access (FDI vs. acquisition). Another paper by Schnitzer (1999) analyzes how the investor can use his control rights to protect his investment if he faces the hold-up problem. However, all these papers do not examine the strategic timing of the technology transfer, that is, the amount and the pace of technology transfer in a dynamic model. Furthermore, in extensions to our model, we explore the effects of uncertainty and shocks on the market structure. To some degree, this continues the earlier works on the same topic; for example, Rob and Vettas (2003) that examine the choice between FDI and exports under the assumption of demand uncertainty and irreversibility of investment. Also, Kotseva and Vettas (2005) study the choice between FDI and exports in presence of demand shocks that, while increasing expected profits, impede learning because of persistence of uncertainty. However, in these earlier papers there was no technology transfer, which in our newer model has an effect on the endogenous formation of the vertical chain.

[6] Another strand of the literature examines the vertical contractual relations and how the various types of vertical contracts affect the final and intermediate prices and the competition in both vertical levels (for a general review, see Motta (2004)). Pack and Saggi (2001) find that the double marginalization problem in a vertical chain is reduced when technology is transferred via international outsourcing and diffusion leads to entry in the domestic country market. Our model is related to that literature and especially to the exclusivity of relations between the upstream and downstream firms. Rey and Tirole (2007) focus on vertical market foreclosure, where not all competitors have access to a bottleneck input, while Rey and Verge (2008) offer a comprehensive overview of vertical contacting issues. In our framework, the upstream technology innovator supplies, in equilibrium, a specific downstream firm and leads to downstream foreclosure of the less efficient competitors. Brocas (2003) focuces on how development of technologies with switching costs affects vertical integration. The use of technology transfer to deter entry is analysed in Duchene et al. (2012) There are many papers that examine the exclusivity in a vertical chain (such as, Marx and Shaffer (2007), Fumagalli and Motta (2006)) but, to the best of our knowledge, a dynamic vertical model with technology transfer by an upstream innovator has not been examined.

technology transfer generates cost-lowering spillovers for the competitor, and find that imitation risk may intensify competition. In similar lines, Henry and Ponce (2011) study the dynamic pricing of knowledge by examining the incentives to imitate rather than innovate. More closely related to the topic of voluntary knowledge transfer are Allain *et al.* (2011) who examine the process of selling inventions which can be considered as a case of technology transfer that can happen sooner or be delayed. They find that asymmetric information about the value of invention may lead to deviations from the socially optimal timing of technology transfer, depending on the bargaining power of the innovator. It is interesting that their results are similar to ours, while assumptions differ: in their model the delays are driven by insufficient bargaining power of the innovator, while in our model it is the innovator who has initially all the bargaining power and makes take-it-or-leave-it offers. The intuition would be that any spillover, asymmetry of information, moral hazard or other deviation tends to be a burden on the pace of the efficient technology transfer, regardless whether they are placed upstream or downstream.

In a setting close to ours, Long *et al.* (2009) study a dynamic vertical model where the downstream firm can quit from its contract without penalties and find that the pace of technology transfer in this case deviates from the optimal. In another paper, Long *et al.* (2014) study the effects of imperfect employment contracts on the pace of knowledge that a firm allows its workers to accumulate and find that knowledge accumulation becomes delayed. In both of these papers, authors concentrate on one isolated licensee's or worker's incentives at a time, and do not include in the models a possibility for the upstream agent to hire a replacement after the first contract is broken. Our paper offers a major addition: we introduce the strategic ability to "hire" a new downstream firm if the previous one quits. We believe this is a very realistic assumption that sometimes changes the game dramatically, since the effect of competition reduces the ability of the downstream firm to extort rents due to moral hazard. In addition, by planning the timing of technology transfer, U may gradually affect the market structure itself, making it endogenous. However, we find that the existence of a pool of competing downsteam firms may be insufficient to eliminate the bargaining power of the downstream firm that has already received some technology transfer. This is because once the downstream firm receives some knowledge transfer, he is no longer homogemous and comparable with the other firms. If there are no quick and inexpensive ways to train others to his level and therefore make his solo survival on the Bertrand market unrealistic, the moral hazard tends to remain.

Also a setting that is somewhat similar to ours appears in Garicano and Rayo (2017) who develop a model of apprenticeship within a single vertical chain. Costless knowledge transfer takes place in two phases: an arbitrary transfer in period 1 for which the expert is not compensated by the novice, followed by a certain level of transfer in subsequent periods. The transferred knowledge increases the novice's productivity and enables him to compensate the expert, but at the same time reduces the ability of the expert to retain the apprentice who has an incentive to leave and start his own business. The authors assume that once the vertical chain is dissolved, no other chain can be formed. They find that in equilibrium full surplus is extracted by the expert as a payment for knowledge. Due to incomplete contracts, the transfer of technology is slowed by the expert, so as to extract the maximum rents. The major differences of our paper from Garicano and Rayo (2017) are two. Firstly, we assume that the transfer of knowledge is not costless (and in fact that the adoption cost increases by an increasing rate), which makes it harder for the U firm to extract the surplus and gives some bargaining power to the D firm because of the sunk costs. Secondly, in the case of hold-up we allow for U to try to hire another licensee, which adds an extra strategic element to the game.

Summarizing, our research combines the three strands of literature that are described above. We endogenize the timing of technology transfer in a vertical chain, when licensing occurs under imperfect property rights and explore the role that competition plays in resolving the hold-up problem.

The remainder of the paper is as follows. Section 2 sets up the base model. Vertical integration is examined in Section 3. In Section 4, we present the vertical separation scenario, while Section 5 compares these two alternative scenarios. Finally, in Section 6 we present and discuss extensions of our base model before we conclude in Section 7.

2 The model

There is one upstream firm (U) and a large pool of downstream firms (D, D', ...). The downstream firms have legal permission to operate in the good's market and produce homogeneous goods. Initially, they produce at the same marginal production cost c. Firm U has advanced technology that reduces the production cost of the downstream firms when this technology is transferred to them. This cost reduction is cumulative as the technology transfer of the previous period continues to contribute to the cost reduction in the future. We examine a two-period model ($t = 1, 2$) where the discount factor is denoted by $\delta \in [0, 1]$. Therefore, the production cost of the downstream firms is equal to $c_1 = c - h_1$ in the first period and $c_2 = c_1 - h_2$ in the second period, where c_t is the marginal cost in period t and h_t is the technology transferred in period t.

Transferring technology is costly, think of training costs necessary to adopt the new technology. As technology transfer increases, the adoption cost increases in an increasing rate. This cost is reflected by a quadratic function $C(h_t) = \frac{\tau h_t^2}{2}, \tau \geq 0$ and is paid by U. Assume an inelastic demand function $Q = k$, where the reservation value v of the buyers surpasses the initial production cost c.[7] The type of competition in the good's market is Bertrand. Finally, U charges fixed fees, a lump-sum transfer F_t, to the downstream firms when transferring technology h_t. We assume that there are cash constraints, therefore, the fixed fee F_1 may not be drawn from the expected downstream profits in the subsequent period.

We start our analysis by studying the benchmark case, where U is vertically integrated (VI) with D and no fees are paid when technology is transferred within the VI chain. The timing of the game is as follows. In the first period, U chooses the level of technology transfer h_1 to its VI partner and then the downstream firms compete in the final market by setting the final price p_1. In the second period, U chooses the level of technology transfer h_2 and then the final price p_2 is set by the downstream firms. Vertical separation (VS) is studied in Section 4, where U charges a fixed fee F_t when technology h_t is transferred. The game becomes:

1.1 First period. Firm U makes a take-it-or-leave-it offer to the downstream firms, consisting of the level of technology transfer h_1 and the compensation fee F_1. Since there is a large pool of symmetric downstream firms and there are cash constraints, U chooses randomly to supply, say the downstream firm D. Thus, D produces with a reduced cost in the first period.[8]

1.2 First period. Downstream firms compete à la Bertrand and the final price p_1 is set. D pays the agreed compensation fee F_1 to U.

2.1 Second period. U makes a take-it-or-leave-it offer (h_2, F_2) to firm D and D decides whether to stop dealing with U or not, i.e, to reject or accept the offer. If D rejects the offer, no further technology is transferred to D. U then may make a take-it-or-leave-it offer (h_2', F_2') to another downstream firm, say D'.

2.2 Second period. Downstream firms compete à la Bertrand by setting the product price p_2.

[7] We use inelastic demand in order to avoid the effect of price on demand, concentrating instead on the technology effect. We have also studied the elastic demand case P=a-Q partly for some parameter values (a>2c in order to avoid that the reduced monopoly price is lower than the initial cost c) and the results were qualitatively similar.

[8] Note that U transfers technology to only one firm each period. Downstream firms compete à la Bertrand and the more cost efficient firm obtains the whole demand each period.

The compensation fee is paid to U.

The game is solved by backwards induction.

3 Vertical Integration

In this vertical structure, the VI firms, U and D, maximize their joint profits.[9] We solve the game backwards starting from the second period. Given that in the first period, U has transferred technology h_1 to its downstream partner D, in the second period U never transfers technology to another downstream firm, apart from its own D, since the downstream firms compete in prices in the final market and the firm with the lower cost obtains the whole demand. Therefore, in the second period downstream firm D is the more cost efficient firm with production cost $c_2 = c - h_1 - h_2$ and the final price is set at the initial level of the production cost c, $p_2^{VI} = c$.[10] Then, the VI chain chooses the level of h_2 by maximizing their joint profit

$$\Pi_2^{VI} = (p_2 - c_2)Q - \frac{\tau h_2^2}{2} = (h_1 + h_2)k - \frac{\tau h_2^2}{2}. \tag{1}$$

From the first order conditions, we obtain

$$h_2 = \begin{cases} \frac{k}{\tau} & if \quad 0 \leq h_1 \leq c - \frac{k}{\tau} \\ c - h_1 & if \quad c - \frac{k}{\tau} < h_1 \leq c. \end{cases} \tag{2}$$

The second order conditions are satisfied ($d\Pi_2^{VI}/dh_2 = -\tau$).[11] Note that the production costs cannot be negative, thus, we have $c_t \geq 0$ for $t = 1, 2$ or equilvalently $h_1 + h_2 \leq c$ and $h_1 \leq c$. Whenever, $c_2 \geq 0$ is not satisfied (for high h_2 derived by the first order conditions, $k/\tau > c - h_1$), due to the concavity of the profit function Π_2^{VI}, the equilibrium level of h_2 is set at the maximum possible level, that is, $h_2 = c - h_1$. Replacing for h_2 into (1), the second period's profit is

$$\Pi_2^{VI} = \begin{cases} \frac{k(k+2\tau h_1)}{2\tau} & if \quad 0 \leq h_1 \leq c - \frac{k}{\tau} \\ \frac{2kc - \tau(c-h_1)^2}{2} & if \quad c - \frac{k}{\tau} < h_1 \leq c. \end{cases} \tag{3}$$

All other downstream firms get zero demand and obtain zero profits.

[9] Suppose the case where a MNE firm U operates its own subsidiary in the foreign local market or that U signs a long-run contract with a single downstream firm for dealing with it in both periods.

[10] Since this is a Bertrand competition game, the price is set on the limit below the initial production cost and the VI chain obtains the whole demand.

[11] The case where $h_1 \leq c - k/\tau$ is only valid when $c - k/\tau > 0$, i.e., $\tau > k/c$.

In the first period, D faces a cost $c_1 = c - h_1$ which is lower than the rest downstream firms' cost c and, thus the final price is set at c, $p_1^{VI} = c$. Then, the VI chain maximizes the present value of their joint profits PV^{VI} with respect to the level of technology transferred in the first period of the game

$$\begin{aligned} PV^{VI} &= \Pi_1^{VI} + \delta\Pi_2^{VI} = (p_1 - c + h_1)k - \frac{\tau h_1^2}{2} + \delta\Pi_2^{VI} \\ &= \begin{cases} h_1 k - \frac{\tau h_1^2}{2} + \delta\left(\frac{k(k+2\tau h_1)}{2\tau}\right) & if \quad h_1 \leq c - \frac{k}{\tau} \\ h_1 k - \frac{\tau h_1^2}{2} + \delta\left(\frac{2kc - \tau(c-h_1)^2}{2}\right) & if \quad h_1 > c - \frac{k}{\tau}. \end{cases} \end{aligned}$$

From the first order conditions, we get

$$h_1 = \begin{cases} c & & \tau \in (0, \frac{k}{c}) \\ \frac{k + c\tau\delta}{\tau(\delta+1)} & if & \tau \in (\frac{k}{c}, \frac{k(2+\delta)}{c}) \\ \frac{k(1+\delta)}{\tau} & & \tau \in (\frac{k(2+\delta)}{c}, \infty). \end{cases}$$

Similarly as in the second period, the production cost c_1 cannot be negative. The second order conditions are satisfied and by summarizing all results for the VI case, we conclude to the following proposition.

Proposition 1 *Under vertical integration, the equilibrium prices are* $p_1^{VI} = p_2^{VI} = c$ *and the equilibrium levels of technology transfer and profits are given by*

Table 1: Equilibrium outcome under Vertical Integration

τ	h_1^{VI}	h_2^{VI}	$h_1^{VI}+h_2^{VI}$	Π_1^{VI}	Π_2^{VI}
$(0, \frac{k}{c})$	c	0	c	$\frac{c(2k-c\tau)}{2}$	ck
$(\frac{k}{c}, \frac{k(2+\delta)}{c})$	$\frac{k+c\tau\delta}{\tau(\delta+1)}$	$\frac{c\tau-k}{\tau(\delta+1)}$	c	$\frac{(k+\delta(2k-c\tau))(k+c\tau\delta)}{2\tau(\delta+1)^2}$	$kc - \frac{(c\tau-k)^2}{2\tau(\delta+1)^2}$
$(\frac{k(2+\delta)}{c}, \infty)$	$\frac{k(1+\delta)}{\tau}$	$\frac{k}{\tau}$	$\frac{k(2+\delta)}{\tau} < c$	$\frac{k^2(1-\delta^2)}{2\tau}$	$\frac{k^2(2\delta+3)}{2\tau}$

When the cost parameter τ is low enough, meaning that the technology transfer is not very costly, the upstream firm transfers technology $h_1 = c$, thus, the marginal production cost is zero from the first period ($c_1 = 0$). For intermediate values of τ, the marginal production cost is reduced to zero in the second period ($c_2 = 0$). But when τ is high enough, the marginal cost never reaches the zero level, since technology transfer is too costly ($c_2 > 0$).

4 Vertical Separation

While we relegate all the details to the Appendix, we now sketch how the game develops under VS where U charges a fixed fee F_t when it transfers technology h_t to a downstream firm. We proceed backwards to solve for the subgame perfect equilibrium.

Stage 2.2 Final prices in the second period In this stage the downstream firms compete by setting the final price p_2 to maximize profits

$$\Pi_2^D = \begin{cases} (p_2 - c_2)k - F_2 \quad if \quad h_2 \text{ is transferred} \\ (p_2 - c_1)k \qquad\qquad\qquad \text{otherwise.} \end{cases}$$

However, this decision depends on the second period's production costs and, thus, on the technology transferred. There are three alternative cases depending on whether technology in the second period is transferred to the same downstream firm D as in the first period, to another downstream firm D' or to no downstream firm.

Consider first the case where D has accepted the offer (h_2, F_2) made by U at Stage 2.1. D has a production cost equal to $c_2 = c - h_1 - h_2$ and all other downstream firms face the initial cost c. Under Bertrand competition, the price p_2 is set at level c. D pays the fee F_2 to firm U, while all other downstream firms obtain zero demand and profits.

In contrast, in the second case, D has rejected the offer (h_2, F_2) made by U and has no further cost reduction in the second period. Nevertheless, U has transferred technology h'_2 to another downstream firm D' that has not dealt with before. Thus, there are two downstream firms with reduced production cost; D with cost $c - h_1$ and D' with cost $c - h'_2$. Note that a necessary condition is that h'_2 is greater than h_1 ($h'_2 > h_1$), so as firm D' to become the more cost efficient firm and have positive demand. Now, the final price is set at $c - h_1$ with D' to obtain the whole demand.

Finally, there can be the case where no technology is transferred at the second period. D is still the more cost efficient firm with cost equal to $c - h_1$, while the other firms have the initial production cost c leading to a price p_2 equal to c.

Stage 2.1 Contract terms in the second period In this stage, U sets the contracts terms (h_2, F_2), that is, sets the level of technology transfer and the payment for the technology transferred in the second period, to maximize its profits

$$\Pi_2^U = \begin{cases} F_2 - \frac{\tau h_2^2}{2} \quad if \quad h_2 \text{ is tranferred} \\ 0 \qquad\qquad\qquad \text{otherwise.} \end{cases} \tag{4}$$

There are four alternative cases, depending on whether U makes an offer to D, such that D is still supplied technology in the second period or not and depending whether D extracts a rent, that is, obtains a positive profit or not. These alternative cases crucially depend on the values of h_1 which are set at the first period. Below, and analytically in the Appendix, we prove that U prefers to transfer technology to the same downstream firm D as in the first period.

Consider first the case where D *is supplied* h_2 *and extracts no rent*. In this case, D accepts the take-it-or-leave-it offer (h_2, F_2) made by U whenever it does not obtain lower profits than the profits obtained by rejecting the offer and producing alone.[12] Here, U could potentially serve another downstream firm D', thus, if D would have rejected the offer, it would have obtained zero profits. Therefore, D accepts any offer that gives non-negative profits. This case holds when U obtains non-negative profits if it served another firm D', that is, when $\Pi_2^U(h_2', F_2') \geq 0$ or alternatively when h_1 is low enough (lower than the "rent bound" as calculated in the Appendix) such that the second period's cost asymmetries, between D and the other downstream firms, are not high enough and it is easy for U to serve another firm D'. Since U has the bargaining power, it offers a fixed fee F_2 to extract all profits by firm D (by setting $\Pi_2^D = 0$). The fixed fee F_2 is used as an instrument to split the profits in the vertical chain, while the level of technology transfer h_2 is used as an instrument to maximize these profits.

In the second case, D *is supplied* h_2 *and extracts rent*. Similarly as before, D accepts the take-it-or-leave-it offer (h_2, F_2) made by U when it obtains at least its outside option. Here, U could not potentially serve another firm D'; this is true for $\Pi_2^U(h_2', F_2') < 0$ or alternatively when h_1 is high enough (higher than the "rent bound"). If D would have rejected the offer, it would obtain positive profits by producing alone. Thus, the offer made by U leaves a positive rent equal to these profits to D; F_2 is determined in this way. Next U determines h_2 by maximizing its profits.

In the third case, D' *is supplied* h_2'. Here, D rejects the offer (h_2, F_2) and U makes an offer (h_2', F_2') to D'. D' accepts the offer when it obtains non-negative profits, since D' has not dealt with U before. Additionally, this case holds when U's profits by dealing with D' are non-negative, that

[12] Thereafter, we assume that if a downstream firm is indifferent between dealing with U and stopping this cooperation, it continues this cooperation.

is, this corresponds to values of h_1 where $\Pi_2^U(h_2', F_2') \geq 0$ (for h_1 lower than the "rent bound"). Firm U extracts all profits by D' through the fixed fee F_2' and maximizes its profits by choosing h_2'. Note also that we need $h_2' > h_1$, otherwise D' obtains zero demand.

The final case is where *no downstream firm is supplied* h_2. D rejects U's offer and U cannot make a new offer (h_2', F_2') to another downstream firm D'. This case corresponds to values of h_1 where $\Pi_2^U(h_2', F_2') < 0$ (for h_1 higher than the "rent bound"). U does not operate in the second period and D enjoys positive profits by operating without further cost reduction.

Thus far, we have derived the contract terms for the various values of the technology transfer h_1 already supplied in the first period to D. However, the equilibrium in Stage 2.1 remains to be derived. Is it more profitable for U to make an offer to D, such that D does not stop dealing with it (by, possibly, giving a positive rent to D) or to make an offer to another downstream firm D'? After comparing U's profits between the first and third case (i.e., when $\Pi_2^U(h_2', F_2') \geq 0$ or h_1 lower than the "rent bound") and between the second and forth cases (i.e., when $\Pi_2^U(h_2', F_2') < 0$ or h_1 higher than the "rent bound"), we find that

Lemma 1 *In the second period, upstream firm U always prefers to transfer technology to the downstream firm D, the one that has already transferred technology in the first period of the game.*

Intuitively, U has already invested in D at the first period of the game and stays with the same firm at the second period, even if it has to leave a positive rent to it.

Stage 1.2 Final prices in the first period Given that U has transferred technology h_1 to D, downstream firms compete à la Bertrand. Since D has a reduced cost $c_1 = c - h_1$, the final price p_1 is set equal to c. Thus, the profit function of D, after paying the fee F_1, is

$$\Pi_1^D = (p_1 - c_1)k - F_1 = h_1 k - F_1, \tag{5}$$

and all other downstream firms obtain zero demand and profits.

Stage 1.1 Contract terms in the first period In this stage, U offers a contract (h_1, F_1) to the downstream firms. Since all downstream firms are initially cost symmetric, U chooses randomly say D to supply h_1. U cannot supply technology to another downstream firm at the same time, since firms compete in prices and only one firm may get positive profits at Stage 1.2. Moreover, U has the bargaining power and extracts all profits by D via $F_1 = h_1 k$ by setting $\Pi_1^D = 0$. U also determines the level of technology h_1 to be transferred to D. This decision does not only affects the current profits of firm U, but also the future profits. When h_1 is low enough, U extracts all profits by D without leaving any positive rent to it in the second period. In contrast, when h_1 is high enough, D extracts some positive rent. Firm U determines h_1 by maximizing the present value of its profits

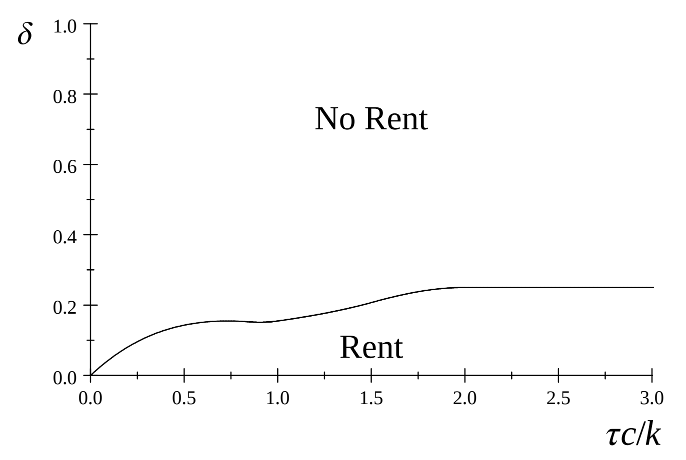
$$PV = \Pi_1^U + \delta\Pi_2^U = h_1 k - \frac{\tau h_1^2}{2} + \delta\Pi_2^U,$$

where δ is the discount factor and Π_2^U is calculated at Stage 2.1, depending on whether D extracts rent or not. In the Appendix, we calculate and present analytically the h_1 that maximizes the present value with no rent extracted by D (PV^{NR}) and the h_1 that maximizes the present value with rent extracted by D (PV^R) and afterwards we compare these present values to determine the optimum h_1. If U supplies a relatively low h_1 to D, the future cost asymmetry, between D and the other downstream firms, is low enough and U extracts the whole profits in the second period of the game. Nevertheless, the investment in cost reduction is low enough, which leads to lower profits in both periods. Thus, there are two effects when reducing the technology transfer in the first period; one that tends to reduce the rent extracted by D and one that increases the production cost in both periods. The opposite reasoning holds for relatively high levels of h_1. We find that

Proposition 2 *Under vertical separation, both the "Rent" and the "No Rent" strategy may arise in equilibrium depending on the parameter values. For relatively low values of the discount factor δ, the "Rent" strategy emerges.*

The next figure shows how the equilibrium strategy, between giving rent or not, changes for different values of the discount factor δ and the cost parameter τ.

Figure 1: Rent vs. No Rent



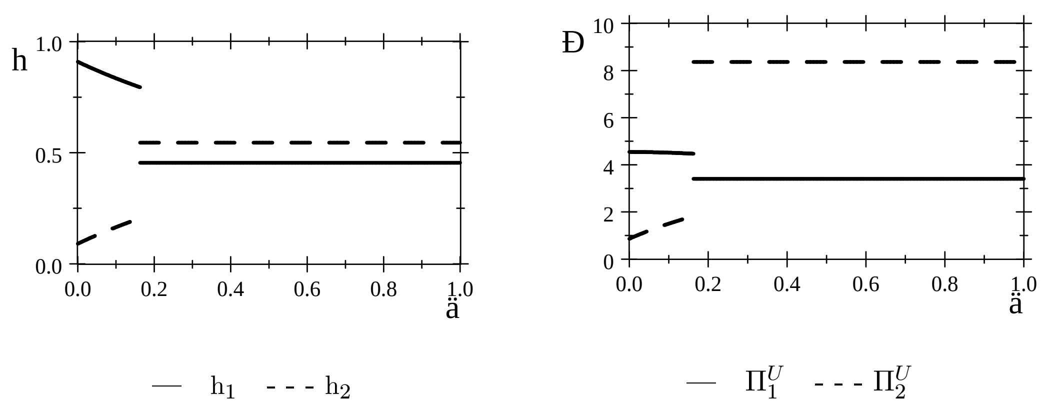
The vertical axis represents the discount factor δ, while the horizontal axis represents $\tau c/k$. Since c/k is a constant, the horizontal axis can be viewed as a proxy for τ (for simplicity you may assume that $c/k = 1$, thus the horizontal axis is exactly τ). The line represents the locus of points where U is indifferent between the strategy of "investing more and giving rent" and the strategy "investing less, so as to give no rent" ($PV^R = PV^{NR}$) Above this line, U prefers the "No Rent" strategy, while below this line U prefers the "Rent" strategy.

When future is not as important ($\delta \to 0$), U transfers a high level of h_1 to D in the first period to enjoy lower marginal cost in this period and, this leads to rent extraction by D in the second period. Note that when $h_1 + h_2 < c$, that is, when τ is sufficiently high ($\tau c/k > 3/2$) and the cost of production is eventually not eliminated, U prefers to give a rent whenever $\delta < 0.25$. Another observation is that the line is decreasing for $\tau c/k \in (0.74, 0.91)$ and increasing otherwise. Therefore, it seems that for a given δ, an increase in τ does not always make the "No Rent" strategy more preferable. There are two countervailing effects at play here. An increase in τ means that technology transfer is costly and should be spread over two periods, therefore less technology transfer will happen within the first period. This decreases the downstream firm's outside option. Thus, it becomes more difficult for the downstream firm to extract a rent, and leads to the "No Rent" strategy. However, on the other hand, this makes the "Rent" strategy more attractive for the upstream firm, since the rent (equal to the outside option) would not be very high.

We also find that for very low values of τ, technology transfer in the first period leads to zero cost ($c_1 = 0$) and for intermediate values of τ, technology transfer reduces the second period's cost to zero ($c_2 = 0$). Thus, production cost reaches it's minimum level, but in the latter case with a delay. Nevertheless, for high values of τ, the second period's cost is not reduced to zero ($c_2 > 0$).

The next numerical example illustrates the equilibrium levels of the technology transfer and the profit for both periods.

Figure 2: Equilibrium technology transfer and profits for every δ and $k = 10, c = 1, \tau = 11$



For these parameter values, the total level of technology transfer of both periods is always equal to the initial cost ($h_1+h_2= c$), meaning that the cost in the second period is reduced at level zero. Nevertheless, the timing of the technology transfer differs with δ. For high levels of the discount factor, the technology transfer is delayed, since the higher level of technology is transferred in the second period, $h_1 < h_2$. Concerning U's profits, for low δ the profits in the first period are higher compared to the second period's profits. The opposite holds for high values of δ.

5 Vertical Integration vs Vertical Separation

Having calculated the equilibrium outcome under VI and VS, we now compare these findings. By direct comparison of the equilibrium level of technology transfer under VI and VS, we find that

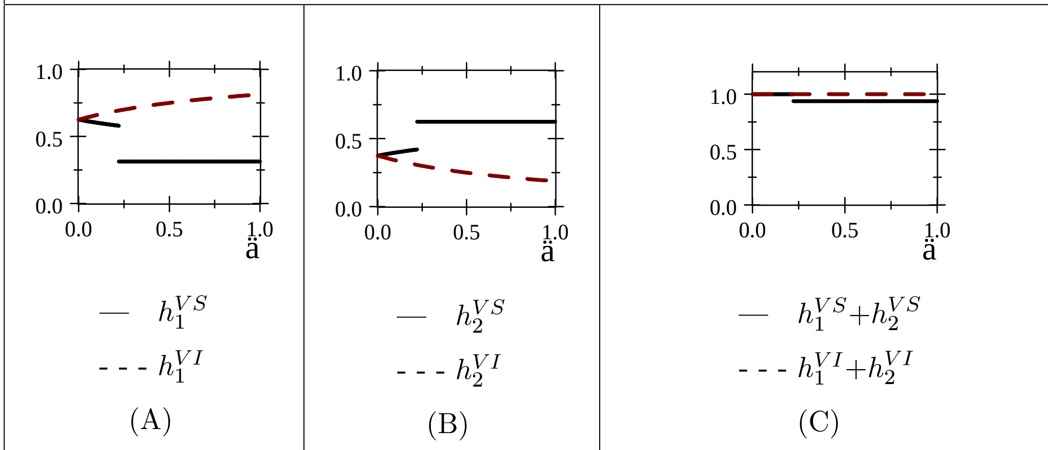
Proposition 3 *Under vertical separation the equilibrium level of technology transfer is never higher and faster than the equilibrium level of technology transfer under vertical integration. We have* $h_1^{VI} \geq h_1^{VS}$ *and* $h_1^{VI} + h_2^{VI} \geq h_1^{VS} + h_2^{VS}$. *The pace of technology transfer differs between the two alternative vertical structures.*

For the first period, the level of technology transfer under vertical separation h_1^{VS} is either lower or equal to the technology transfer of the first period under VI. Under VI, there is no threat that D

will stop dealing with U in the second period of the game, thus, the incentives of U to decrease the technology transfer in the first period are reduced. Under VS, U tends to decrease h_1, compared to the VI case, in an effort to lower the rent paid to D in the second period. If h_1 is low enough, the rent paid reduces to zero. Thus, h_1 is used by U as an instrument to reduce D's bargaining power. Therefore, on the one hand, U decreases or avoids the future rent paid, but, on the other hand, sacrifices some short-run profits due to a smaller cost reduction, that is, U gets a larger share of a smaller pie. In addition, h_1^{VS} is never lower than the "rent bound". When U prefers to give no rent to D, it gives the maximum level of h_1 that allows no rent. Thus, the equilibrium level of h_1 under VS is either above the "rent bound" that generates rent in the second period or exactly at this level.

In Figure 3 we present a numerical example of the level of technology transfer under VS and VI. In Figure 3(A), we observe that h_1^{VI} is higher than the h_1^{VS} and increasing in δ. When future is more important, U increases the technology transferred in its VI partner, that is, it makes a higher investment today to enjoy a lower cost in the future. Under VS, h_1^{VS} is discontinuous in δ since there is the switch from the Rent to the No Rent case. For low δ, a rent is paid to D in the second period of the game, in contrast to the case of high levels of δ. When there is rent extraction by D, h_1^{VS} is decreasing in δ, since U aims in a rent reduction. Nevertheless, when U switches to the No Rent case, h_1^{VS} is set at the maximum level so as to make D indifferent between cooperating with U or not, that is, h_1^{VS} is set at the "rent bound" which is independent of δ, since it is determined by the potential profits of U dealing with a new downstream firm D' in the second period of the game.

Figure 3: Technology transfer under VS and VI for every δ when $k = 10, c = 1, \tau = 16$



Concerning the total level of technology transfer in both periods, it is never higher under VS compared to the VI case ($h_1^{VI} + h_2^{VI} \geq h_1^{VS} + h_2^{VS}$). When τ is sufficiently low, we obtain $h_1^{VI} + h_2^{VI} = h_1^{VS} + h_2^{VS} = c$ and, since $h_1^{VI} \geq h_1^{VS}$, we conclude that the technology transfer under VS is shifted towards the second period. The pace of technology transfer differs between the two alternative vertical structures (VI vs VS). There is a delay in the technology transfer under VS. When τ is sufficiently high, we obtain $c > h_1^{VI} + h_2^{VI} > h_1^{VS} + h_2^{VS}$, thus the reduction in h_1^{VS} is not compensated by an increase of h_2^{VS}. Hold-up issues arise when τ is sufficiently high and therefore it becomes costly to replace firm D that chooses to leave. However, in equilibrium U sticks with D either by paying a rent to D, or by adjusting the amount of the technology transfered in period one so as to diminish D's outside option in period two.

In the numerical example in Figure 3(C), we observe that the cost in the second period of the game is always reduced to zero ($h_1^{VI} + h_2^{VI} = c$), and since h_1^{VI} is increasing in δ, we obtain that h_2^{VI} is decreasing in δ (see Figure 3(B)). Analogously holds for the VS case with rent extraction (low δ). Note also that h_2^{VS} is higher than h_2^{VI}, thus, under VS technology is transferred with a delay. Finally, under VS and high levels of δ, the technology cost parameter τ is high enough that does not allow for a full cost reduction in the second period ($h_1^{VS} + h_2^{VS} < c$).

6 Model extensions

In this section, we explore some extensions of our base model. First, we present the case where different initial costs could be drawn at each firm across periods. Then, we discuss the case with no uncertainty across periods but with a single initial cost efficient firm.[13]

6.1 Different initial production costs across periods

Thus far each downstream firm faces the same initial production cost c in each period. Here, we introduce uncertainty in the initial production cost of each downstream firm across periods. Let the initial production cost of each firm be either low or high and this is determined in the beginning of each period by an i.i.d. draw from $\{c_L, c_H\}$ with probability ρ and $(1 - \rho)$, respectively, which is also publicly known (with $c_L < c_H$). Think of the case where there are random and exogenous

[13] One culd also consider Cournot competition downstream. The principal difference in the Cournot set-up is that more than one firm may produce and sell, despite cost-asymmentry. This allows for additional strategic thinking by U, which might attempt to invest in two downstream firms at once, so as to create a competitive threat for the second period.

shocks that affect the marginal production costs of the retailers. In this case, at the start of each period there are several firms with c_L and several firms with c_H.[14] However, this information is revealed to everyone only in the beginning of each period, thus, firms in the first period do observe all initial costs for this period but not for the subsequent period (including their own cost). We expect that in the first period, U will transfer technology to one of the low cost downstream firms, say D. It is interesting to examine whether D will deal with D in the second period as well and what will be the equilibrium level and pace of technology transfer, since now D may not have an initial cost c_L in the second period.

Under VI, U is locked with his vertically integrated partner. Nevertheless, U might now prefer not signing a long-run contract with the same D each period. U might prefer in the second period to stop dealing with the first period's partner D, if D draws a high cost (that is, has a cost-increasing shock) in the second period. Under VI, U is protected from the rent-seeking behavior of D, thus, the technology transfer h_1 is not reduced to limit the future bargaining power of D. However, U is now exposed to the risk of an unfavorable cost draw of its own downstream partner, since it cannot contract another downstream firm. To compensate for this risk, technology transfer h_1 will be optimally chosen to reflect not only the first period's cost of D, but also the expected cost in the second period according to the probabilities ρ and $1 - \rho$. Next we present the VI case and discuss a numerical example under VS which proves that under cost uncertainty across periods, U might prefer to be vertically separated and more flexible on which downstream firm to deal with than vertically integrated and locked with the same partner forever.

Vertical Integration Let the VI partner D be a low cost in the first period. In the second period, the cost of all downstream firms is revealed, technology is transferred and then the downstream firms compete in prices. There are several firms with c_L and several firms with c_H. If the cost of the initial VI partner D continues to be c_L, the results replicate the results of our base model (now $c_2^{VI} = c_L - h_1 - h_2$). Therefore, price is set at $p_2^{VI} = c_L$ and the technology transfer and profits of the VI chain in the second period are taken by (2) and (3) with c_L instead of c.

However, if the cost drawn to the VI partner D is c_H, the optimal technology transfer changes. The VI chain faces $c_2^{VI} = c_H - h_1 - h_2$ and D is the more cost efficient firm and serves the market,

[14] Since there is a pool of downstream firms, we do not focus on the case where only one downstream firm happens to be more cost efficient compared to all other downstream firms in the pool. In the next subsection, we discuss the case where only one downstream firm has a low initial cost compared to all other downstream firms that have high initial costs - but there is no uncertainty across periods, so each downstream firm has the same initial cost each period.

if and only if $c_2^{VI} \leq c_L$ or, by rewriting, $h_2 \geq (c_H - c_L) - h_1$. The technology transfer should be high enough to cover the increase in the production cost due to the shock, otherwise the VI chain cannot obtain positive demand. The price is set at $p_2^{VI} = c_L$ and the VI chain's profits are given by

$$\Pi_2^{VI-HIGH} = \begin{cases} 0 & if \quad h_2 < (c_H - c_L) - h_1 \\ (c_L - c_H + h_1 + h_2)k - \frac{\tau h_2^2}{2} & if \quad (c_H - c_L) - h_1 \leq h_2 \leq c_H - h_1. \end{cases} \tag{6}$$

The VI chain maximizes its profit with respect to h_2. By the first order conditions, the constraint $0 \leq c_2^{VI} \leq c_L$ and the concavity of (6), we obtain

$$h_2^{VI-HIGH} = \begin{cases} 0 & & h_1 \leq (c_H - c_L) - \frac{k}{\tau} \\ \frac{k}{\tau} & if & (c_H - c_L) - \frac{k}{\tau} < h_1 \leq c_H - \frac{k}{\tau} \\ c_H - h_1 & & c_H - \frac{k}{\tau} < h_1 \leq c_L. \end{cases}$$

Replacing for h_2 into (6), the second period's profts for the VI chain become[15]

$$\Pi_2^{VI-HIGH} = \begin{cases} 0 & & h_1 \leq (c_H - c_L) - \frac{k}{\tau} \\ (c_L - c_H + h_1 + \frac{k}{\tau})k - \frac{k^2}{2\tau} & if & (c_H - c_L) - \frac{k}{\tau} < h_1 \leq c_H - \frac{k}{\tau} \\ c_L k - \frac{\tau(c_H - h_1)^2}{2} & & c_H - \frac{k}{\tau} < h_1 \leq c_L. \end{cases} \tag{7}$$

Note that when the cost difference $(c_H - c_L)$ is high enough and h_1 is low enough, the VI chain cannot obtain positive demand.

In the first period, the VI chain faces an initial cost c_L and becomes the more cost efficient downstream firm due to the technology transfer h_1. The price is set at $p_1^{VI} = c_L$. Then, solving backwards, the VI chain maximizes the present value of its profits, PV^{VI}, with respect to the level of technology transferred in the first period, where

$$\begin{aligned} PV^{VI} &= \Pi_1^{VI} + \delta\left(\rho\Pi_2^{VI-LOW} + (1-\rho)\Pi_2^{VI-HIGH}\right) \\ &= h_1 k - \frac{\tau h_1^2}{2} + \delta\left(\rho\Pi_2^{VI-LOW} + (1-\rho)\Pi_2^{VI-HIGH}\right) \end{aligned}$$

and Π_2^{VI-LOW}, $\Pi_2^{VI-HIGH}$ are replaced by (3) with c_L instead of c and (7), respectively.

[15] The branch where $h_1 \leq (c_H - c_L) - \frac{k}{\tau}$, is only valid when $(c_H - c_L) - \frac{k}{\tau} > 0$, i.e., $\tau > \frac{k}{c_H - c_L}$.

The equilibrium outcome depends on how important is the negative shock to the cost, that is, the relative size of c_L and c_H. For simplicity, we study the case where $c_H = 2c_L$. In this case, the equilibrium level of technology transfer is given by the following table.

Table 2: Equilibrium outcome under VI with different costs across periods

τ	h_1^{VI}	h_2^{VI-LOW}	$h_2^{VI-HIGH}$
$(0, \frac{k(2+\delta)}{c_L(2+\delta\rho)})$	c_L	0	c_L
$(\frac{k(2+\delta)}{c_L(2+\delta\rho)}, \frac{k(1+\delta-\delta\rho)}{c_L})$	c_L	0	$\frac{k}{\tau}$
$(\frac{k(1+\delta-\delta\rho)}{c_L}, \frac{k(2+\delta)}{c_L})$	$\frac{k+k\delta(1-\rho)+c_L\tau\delta\rho}{\tau(\delta\rho+1)}$	$\frac{c_L\tau-k-k\delta(1-\rho)}{\tau(\delta\rho+1)}$	$\frac{k}{\tau}$
$(\frac{k(2+\delta)}{c_L}, \infty)$	$\frac{k(1+\delta\rho)}{\tau}$	$\frac{k}{\tau}$	0

We can compare this case (Table 2) to the VI case with stable (low) cost across periods, that is, when there is no possibility for a negative shock in the cost (Table 1 with $c = c_L$). By direct comparison of h_1, we find that h_1 is lower when negative shocks are possible. The higher expected cost lowers the expected PV and, thus, lowers the technology transfer in the first period.

Vertical Separation As mathematical calculations and presentation of subcases are becoming too complicated in this extension of the base model, we will present a numerical argument to explain why for the upstream firm vertical separation can sometimes be more beneficial than vertical integration.

From Table 2, observe that if the probability ρ is sufficiently small and technology transfer is sufficiently difficult, that is, in this subsection focus on the parameter values where $\tau \in (\frac{k(2+\delta)}{c_L}, \infty)$, then the VI chain will not be able to produce in the second period. This is because the shock increase in the cost of production becomes so high that it cannot be negated by technology transfer (thus, $h_2^{VI-HIGH} = 0$) and therefore production becomes unprofitable. In this case, the only remedy would be to drop the downstream firm that has suffered a cost shock and to form a new chain with one of those firms that have drawn low cost. However, the VI upstream firm cannot break the chain and hence must forfeit the second period profit. On the contrary, a firm U that can adapt to the second period shock by switching to a low cost downstream firm, transfers $h_2 = \frac{k}{\tau}$ and receives profit $\Pi_2^{VS} = h_2 k - \frac{\tau h_2^2}{2} = \frac{1}{2}\frac{k^2}{\tau}$.[16]

To explore the possible magnitude of this effect that disadvantages the VI firm, let us examine

[16] Price is set at c_L since we assume that there are several firms with cost c_L (at least two here).

a special case numerically. Suppose that $\rho \longrightarrow 0$, that is, the cost shock is almost certain to occur. Also suppose that $\delta \rightarrow 1$, that is, the second period matters almost as much as the first period. Under VI, from the last line of Table 2, we have $h_2^{VI-HIGH} = 0$ and $\lim_{(\rho,\delta)=(0,1)} h_1^{VI} = \frac{k}{\tau}$, thus, $\lim_{(\rho,\delta)=(0,1)} PV(VI) = \Pi_1^{VI} = \left(h_1 k - \frac{\tau h_1^2}{2}\right) = \frac{1}{2}\frac{k^2}{\tau}$. This means that the VI firm treats its first period as its last.

Compare this result with the PV of profits of a VS firm that can adapt to the second period shock by switching to a low cost downstream firm. The present value of the second period profits where only the VS firm can participate is: $\lim_{(\rho,\delta)=(0,1)} (1-\rho)\delta\frac{1}{2}\frac{k^2}{\tau} = \frac{1}{2}\frac{k^2}{\tau}$. Therefore, assuming also positive first period profits for the VS firm, $PV(VI) < PV(VS)$. This leads to the next proposition.

Proposition 4 *When a cost shock is possible, there exist parameter values where U prefers to be vertically separated rather than vertically integrated.*

When cost shocks are present, it appears that sometimes U prefers to be vertically separated and sometimes vertically integrated. Under VS, U might have to share the profits with D, whereas, under VI, there is the risk to experience a shock in D's cost.

6.2 Single initial cost efficient firm

Consider now the case where there is no uncertainty across periods, that is, each firm faces the same initial cost each period. Three possible settings emerge. In the first setting, there are many firms with high initial cost and only one with low initial cost, thus, initially there is a single more efficient firm in the pool. In the second setting, there are many firms with low initial cost and only one with high, thus, initially there is a single less efficient firm in the pool. Finally, in the third setting, there are many (at least two) initially high cost firms and many (at least two) initially low cost firms. Note that the second and third setting are qualitatively the same to our (two-period) base model where all firms face the same initial cost, since the addition of the high cost firm/s does not actually alter the model characteristics when sufficient (at least two) low cost firms exist.

In the first setting, it is interesting to examine whether U transfers technology to the most efficient downstream firm in the first period. A possible reason to depart from licensing the most efficient firm is to maintain a competitive threat for the second period. In other words, U might prefer to keep in store an efficient potential licensee so as to discipline the actual licensee and to prevent the latter from extracting a high rent in the second period. After solving the game numerically for a wide range of the parameter values, we did not find a single numerical example where U would prefer to transfer technology to the less efficient firm in the first period.[17] Therefore, it seems that the ability of U to reduce the level of technology transfer serves as a better instrument of controlling D's bargaining power (let D be the low cost firm), than choosing a less efficient downstream firm outright. The intuition could be that the initial cost efficiency of D comes for free. Since U has sufficient power to discipline D by decreasing the technology transfer, it can enjoy the initial cost saving of the efficient firm for free. There could be indeed an advantage in having an initial weak licensee with low bargaining power and an effective potential licensee in store. However, this advantage is more than offset by the need to pay to make the initial licensee competitive.

7 Conclusion

Our paper contributes to three literatures, on technology licensing, on FDI and on vertical contracting. We have studied a model where an upstream monopolist has a cost reducing superior technology that sells to the downstream market which consists of a competitive fringe of initially symmetric firms. The protection of the intellectual property rights is imperfect, therefore, the vertical contracts are incomplete and the downstream firms may stop dealing with the upstream firm without fully compensating the upstream firm for the benefits that have received. The downstream firms compete in the good's market à la Bertrand and the firms that have paid for technology are more cost efficient. We solve a two period model to determine the pace and the timing of the technology transfer, while the structure of the downstream market is determined endogenously.

An exclusive contractual relation with a single downstream firm in both periods prevails in equilibrium. The upstream firm transfers technology to a single and the same downstream firm each period. Unless all technology is transferred in the first period, there is a delay in technology transfer compared to the VI case. This delay is due to the fact that the upstream firm is trying to limit the downstream firm's bargaining power, in an effort to pay less or no rent in the second period. Moreover, when the second period's production cost is not reduced to zero, the total sum of technology transferred is less than in the VI case. For some parameter values, the downstream firm that deals with the upstream firm extracts a rent in the second period of the game since it faces a lower production cost compared to the other downstream firms due to the technology transferred in the first period. We obtain that the upstream firm tends to give rent to the downstream firm for

[17] Matlab files are available by the authors upon request.

relatively low values of the discount factor since future is not very important. Overall, competition downstream is not able to resolve the hold-up problem created by the imperfect intellectual property rights. In an extension, we examine the introduction of uncertain production costs across periods. In that case, it may no longer hold that the upstream firm would want to contract with the same firm each period.

References

[1] Allain M.-L., Henry E., Kyle M. (2015): "Competition and the efficiency of markets for technology", *Management Science*, 62(4):1000-1019.

[2] Brocas I. (2003): "Vertical integration and incentives to innovate". *International Journal of Industrial Organization*, 21:457-488.

[3] Duchene A., Sen D. and Serfes K. (2015): "Technology transfer and entry deterrence". Economica, 82: 1324-1348.

[4] Ethier W., Markusen J. (1996): "Multinational firms, technology diffusion and trade", *Journal of International Economics*, 41:1-28.

[5] Felli L., Roberts K. (2000): "Competition and hold-ups", Chapter 4, in "Putting Economics to Work: Volume in Honour of Michio Morishima", Tony Atkinson, Howard Glennester and Nicholas Stern (eds.), London.

[6] Fosfuri A., Motta M. and Ronde T. (2001): "Foreign Direct Investment and Spillover through Workers' Mobility", *Journal of International Economics*, 53(1): 205-222.

[7] Fumagalli C., Motta M. (2006): "Exclusive dealing and entry, when buyers compete", *The American Economic Review*, 96(3): 785-795.

[8] Garicano L. and Rayo L. (2017): "Relational knowledge transfers". *American Economic Review*, 107(9):2695-2730.

[9] Glass A. J., Saggi K. (2002a): "Multinational firms and technology transfer", *The Scandinavian Journal of Economics*, 104(4): 495-513.

[10] Glass A. J., Saggi K. (2002b): "Intellectual property rights and foreign direct investment", *Journal of International Economics*, 56: 387–410.

[11] Glass A. J., Saggi K. (2008): “The role of foreign direct investment in international technology” in International Handbook of Development Economics ed. by Dutt A. and Ros J.

[12] Henry E., Ponce C. (2011): "Waiting to imitate: on the dynamic pricing of knowledge", *Journal of Political Economy,* 119(5): 959-981.

[13] Horstmann I., Markusen J. (1996): “Exploring new markets: direct investment, contractual relations and the multinational enterprise”, *International Economic Review*, 37:1-19.

[14] Kotseva R., Vettas N. (2005): “Foreign direct investment and exports dynamis with demand learning” CEPR discussion paper No. 5262.

[15] Lin P., Saggi K. (1999): “Incentives for foreign direct investment under imitation”, *Canadian Journal of Economics*, 32:1275-1298.

[16] Long N.V., Soubeyran A., Soubeyran R. (2009): "The pace of technology transfer in anticipation of joint venture breakup" Working Papers 2009.102, Fondazione Eni Enrico Mattei..

[17] Long N.V., Soubeyran A., Soubeyran R. (2014): "Knowledge accumulation within an organization". *International Economic Review*, 55(4):1089-1128

[18] Markusen J. (2001): “Contracts, intellectual property rights, and multinational investment in developing countries”, *Journal of International Economics*, 53:189-204.

[19] Marx L. and G. Shaffer (2007): "Upfront payments and exclusion in downstream markets", *The Rand Journal of Economics*, 38(3), 823-843.

[20] Mattoo A., Olarreaga M., Saggi K. (2004): “Mode of foreign entry, technology transfer and FDI policy”, *Journal of Development Economics*, 75:95-111.

[21] Motta M. (2004): “Vertical restraints and vertical mergers” Ch. 6 at Competition policy: Theory and practice

[22] Mőller T., Schnitzer M. (2006): “Technology transfer and spillovers in international joint ventures”, *Journal of International Economics*, 68: 456– 468

[23] Nocke V., Yeaple S. (2007): “Cross-border mergers and acquisitions vs. Greenfield foreign direct investment: The role of firm heterogeneity”, *Journal of International Economics*, 72: 336–365.

[24] Pack H., Saggi K. (2001): “Vertical technology transfer via international outsourcing”, *Journal of Development Economics*, 65: 389–415

[25] Rey P. and Tirole J. (2007): “A Primer on Foreclosure”, Handbook of Industrial Organization III, ed. by Armstrong M. and Rob Porter R.

[26] Rey P. and Th. Verge (2008) “Economics of Vertical Restraints”, ch. 9 in Handbook of Antitrust Economics, ed. By P. Buccirossi, MIT Press.

[27] Rob R., Vettas N. (2003): “Foreign Direct Investment and Exports with Growing Demand”, *Review of Economic Studies*, 70: 629-648.

[28] Saggi K. (2002): “Trade, foreign direct investment, and international technology transfer: A survey”, The World Bank Research Observer, 17(2): 191-235.

[29] Schnitzer M. (1999): “Expropriation and control rights: A dynamic model of foreign direct investment”, *International Journal of Industrial Organization*, 17:1113–1137.

Appendix: Full analysis of the vertical separation case

Stage 2.2 Final prices in the second period There are three alternative cases depending on whether technology in the second period is transferred to the same downstream firm D as in the first period, to another downstream firm D' or to no downstream firm. We present each case separately.

Case 1: D is supplied h_2. D has accepted the offer (h_2, F_2) made by U at Stage 2.1 and faces cost $c_2 = c - h_1 - h_2$. The price p_2 is set at level c and the profit function for D is

$$\Pi_2^D = (p_2 - c + h_1 + h_2)k - F_2 = (h_1 + h_2)k - F_2. \tag{8}$$

Note that D pays the fee F_2 to firm U, while all other downstream firms obtain zero demand and profits.

Case 2A: D' is supplied h_2'. Here, U has transferred technology h_2' to another downstream firm D' that has not dealt with before. There are two downstream firms with reduced production cost (D' is more efficient) and the final price is set at $c - h_1$. D' obtains the whole demand and gets profits

$$\Pi_2^{D'} = (p_2 - c + h_2')k - F_2' = (h_2' - h_1)k - F_2'. \tag{9}$$

Note that D' pays the fee F_2' to firm U. Firm D and all other downstream firms get zero profits.

Case 2B: No downstream firm is supplied h_2. In this case, no technology is transferred at the second period. The price p_2 is set at c and the profit function for D is

$$\Pi_2^D = (p_2 - c + h_1)k = h_1 k, \tag{10}$$

with all other downstream profits being zero.

Stage 2.1 Contract terms in the second period We present the four alternative cases and prove that U prefers to transfer technology to the same downstream firm D that have dealt with in the first period.

Case 1A: D is supplied h_2 and extracts no rent. In this case, since U has the bargaining power, it offers a fixed fee F_2 to extract all profits by D. By (8), we have $\Pi_2^D = 0$ when

$$F_2 = (h_1 + h_2)k.$$

Replacing for F_2 into (4), we have

$$\Pi_2^U (h_2, F_2) = (h_1 + h_2)k - \frac{\tau h_2^2}{2}. \tag{11}$$

U maximizes its profit with respect to h_2 and by the first order condition, we obtain

$$h_2 = \begin{cases} \frac{k}{\tau} & if \quad 0 < h_1 \leq c - \frac{k}{\tau} \\ c - h_1 & if \quad c - \frac{k}{\tau} < h_1 \leq c. \end{cases}$$

As under VI, the production cost cannot be negative, thus, we have $h_1 + h_2 \leq c$. Whenever, this constraint is not satisfied (for high h_2 derived by the first order conditions, $k/\tau > c - h_1$), due to the concavity of the profit function Π_2^U, the equilibrium level of h_2 is set at the maximum possible level, that is, $h_2 = c - h_1$. Replacing for h_2 into (11), we obtain

$$\Pi_2^U (h_2, F_2) = \begin{cases} \frac{k(k+2\tau h_1)}{2\tau} & if \quad 0 < h_1 \leq c - \frac{k}{\tau} \\ \frac{2kc - \tau(c-h_1)^2}{2} & if \quad c - \frac{k}{\tau} < h_1 \leq c, \end{cases}$$

where $\Pi_2^U > 0$.[18,19] It remains to calculate the values of h_1 where $\Pi_2^U(h_2', F_2') \geq 0$, after deriving the optimum h_2' and F_2' in Case 2A below. We need to find the maximum value of h_1 which would allow U not to leave a rent at firm D in equilibrium. When h_1 is low enough, the second period's cost asymmetries, between D and the other downstream firms, are not high enough and it is easy for U to serve another firm D'.

Case 1B: D is supplied h_2 and extracts rent. If D would have rejected the offer, it would obtain positive profits equal to h_1k, as calculated at Stage 2.2. Thus, the offer made by U leaves a positive rent equal to h_1k to firm D

$$\Pi_2^D = h_1 k.$$

By replacing this into (8), we have

$$F_2 = (h_1 + h_2)k - h_1 k = h_2 k.$$

Moreover, U determines h_2 by maximizing

$$\Pi_2^U(h_2, F_2) = h_2 k - \frac{\tau h_2^2}{2}. \tag{12}$$

From the first order condition, we obtain

$$h_2 = \begin{cases} \frac{k}{\tau} & if \quad 0 < h_1 \leq c - \frac{k}{\tau} \\ c - h_1 & if \quad c - \frac{k}{\tau} < h_1 \leq c. \end{cases}$$

Replacing for h_2 into (12), we have

$$\Pi_2^U(h_2, F_2) = \begin{cases} \frac{k^2}{2\tau} & if \quad 0 < h_1 \leq c - \frac{k}{\tau} \\ \frac{(c-h_1)(2k-c\tau+\tau h_1)}{2} & if \quad c - \frac{k}{\tau} < h_1 \leq c, \end{cases}$$

where $\Pi_2^U > 0$. It remains to calculate the values of h_1 where $\Pi_2^U(h_2', F_2') < 0$.

Case 2A: D' is supplied h_2'. Here, U extracts all profits by D' through the fixed fee F_2'. By (9), we have $\Pi_2^{D'} = 0$ when

$$F_2' = \left(h_2' - h_1\right) k.$$

[18] In all cases in Stage 2.1 the second order conditions are satisfied, since $d\Pi_2^U / dh_2^2 = -\tau$.

[19] The case where $h_1 \leq c - k/\tau$ is only valid when $\tau > k/c$.

Thus, U sets h_2' to maximize its profits

$$\Pi_2^U\left(h_2', F_2'\right) = \left(h_2' - h_1\right)k - \frac{\tau(h_2')^2}{2}. \tag{13}$$

From the first order conditions, we obtain

$$h_2' = \begin{cases} \frac{k}{\tau} & if \quad \frac{k}{\tau} \leq c \\ c & if \quad \frac{k}{\tau} > c. \end{cases}$$

We further need $h_2' > h_1$, otherwise D' obtains zero demand. Replacing for h_2' into (13), we get

$$\Pi_2^U\left(h_2', F_2'\right) = \begin{cases} \frac{k(k-2\tau h_1)}{2\tau} & if \quad \frac{k}{\tau} \leq c \\ \frac{2k(c-h_1)-\tau c^2}{2} & if \quad \frac{k}{\tau} > c. \end{cases}$$

Finally, profits should be non-negative, $\Pi_2^U\left(h_2', F_2'\right) \geq 0$, otherwise U would not supply D'. Taking this into account, we obtain

$$\Pi_2^U\left(h_2', F_2'\right) = \begin{cases} \frac{k(k-2\tau h_1)}{2\tau} & if \quad \frac{k}{\tau} \leq c \text{ and } h_1 \leq \frac{k}{2\tau} \\ \frac{2k(c-h_1)-\tau c^2}{2} & if \quad \frac{k}{\tau} > c \text{ and } h_1 \leq \frac{c(2k-c\tau)}{2k}, \end{cases}$$

where $\Pi_2^U\left(h_2', F_2'\right) \geq 0$ and $h_2' > h_1$ is satisfied. We have determined the "rent bound" for h_1; this equals $k/2\tau$ when $\tau \geq k/c$ or $c\left(2k - c\tau\right)/2k$ when $\tau < k/c$. If the transfer h_1 is lower than this bound, U can supply firm D' in the second period and can obtain positive profits, while D obtain zero profits. U has supplied D with a relatively low h_1 at the first period, thus, cost asymmetries are not high in the second period and it is not too costly for U to transfer technology to D'. Therefore, for these values of h_1, D would not extract a positive rent if it has accepted the offer by U. The opposite holds for h_1 higher than the "rent bound".

Case 2B: No downstream firm is supplied h_2. Here, U does not operate in the second period and D enjoys positive profits equal to $h_1 k$.

Therefore, we conclude that Case 1A and 2A hold when $\Pi_2^U\left(h_2', F_2'\right) \geq 0$; equivalently $h_1 \leq k/2\tau$ for $\tau \geq k/c$ or $h_1 \leq c\left(2k - c\tau\right)/2k$ for $\tau < k/c$. While Case 1B and 2B hold when $h_1 \leq k/2\tau$ for

$\tau \geq k/c$ or $h_1 \leq c\,(2k - c\tau)/2k$ for $\tau < k/c$. In Table A1, we summarize these results.

Table A1: Equilibrium in period 2

		Case 1A equil. with no rent		**Case 2A**	
τ	h_1	h_2	Π_2^U	h_2'	Π_2^U
$(0,\frac{k}{c})$	$h_1 < \frac{c(2k-c\tau)}{2k}$	$c-h_1$	$\frac{2kc-\tau(c-h_1)^2}{2}$	c	$\frac{2k(c-h_1)-\tau c^2}{2}$
$(\frac{k}{c},\frac{3k}{2c})$	$h_1 \leq c-\frac{k}{\tau}$	$\frac{k}{\tau}$	$\frac{k(k+2\tau h_1)}{2\tau}$	$\frac{k}{\tau}$	$\frac{k(k-2\tau h_1)}{2\tau}$
	$c-\frac{k}{\tau} < h_1 < \frac{k}{2\tau}$	$c-h_1$	$\frac{2kc-\tau(c-h_1)^2}{2}$	$\frac{k}{\tau}$	$\frac{k(k-2\tau h_1)}{2\tau}$
$(\frac{3k}{2c},\infty)$	$h_1 < \frac{k}{2\tau}$	$\frac{k}{\tau}$	$\frac{k(k+2\tau h_1)}{2\tau}$	$\frac{k}{\tau}$	$\frac{k(k-2\tau h_1)}{2\tau}$
		Case 1B equil. with rent		**Case 2B**	
τ	h_1	h_2	Π_2^U	h_2	Π_2^U
$(0,\frac{k}{c})$	$\frac{c(2k-c\tau)}{2k} < h_1 < c$	$c-h_1$	$\frac{(c-h_1)(2k-c\tau+\tau h_1)}{2}$	0	0
$(\frac{k}{c},\frac{3k}{2c})$	$\frac{k}{2\tau} < h_1 < c$	$c-h_1$	$\frac{(c-h_1)(2k-c\tau+\tau h_1)}{2}$	0	0
$(\frac{3k}{2c},\infty)$	$\frac{k}{2\tau} < h_1 < c-\frac{k}{\tau}$	$\frac{k}{\tau}$	$\frac{k^2}{2\tau}$	0	0
	$c-\frac{k}{\tau} < h_1 < c$	$c-h_1$	$\frac{(c-h_1)(2k-c\tau+\tau h_1)}{2}$	0	0

After comparing U's profits between Case 1A to 2A and between Case 1B to 2B by taking the relevant expressions from Table A1, we prove Lemma 1. The equilibrium of this stage is given by either Case 1A, when no rent is extracted by D, or by Case 1B, when rent is extracted by D.

Stage 1.2 Final prices in the first period The decisions in this stage are analyzed in the main body of the paper. The final price p_1 is set equal to c and the profit function of D is given by (5).

Stage 1.1 Contract terms in the first period In this stage, U offers a contract (h_1, F_1) and extracts all profits by D via $F_1 = h_1 k$ by setting $\Pi_1^D = 0$. U also determines the level of technology h_1 to be transferred to D by maximizing the present value of its profits. We have the following cases.

Case 1A: No rent extracted by D in the second period. Firm U leaves no rent to firm D, since h_1 is sufficiently low and U could potentially transfer technology to another downstream firm. Firm

U solves

$$\max_{h_1} PV^{NR} = \Pi_1^U + \delta\Pi_2^U$$
$$= \begin{cases} h_1k - \frac{\tau h_1^2}{2} + \delta\left(\frac{2kc-\tau(c-h_1)^2}{2}\right) & \tau \in (0, \frac{k}{c}) \text{ and } h_1 \leq \frac{c(2k-c\tau)}{2k} \\ h_1k - \frac{\tau h_1^2}{2} + \delta\left(\frac{k(k+2\tau h_1)}{2\tau}\right) \quad if & \tau \in (\frac{k}{c}, \frac{3k}{2c}) \text{ and } h_1 \leq c - \frac{k}{\tau} \\ h_1k - \frac{\tau h_1^2}{2} + \delta\left(\frac{2kc-\tau(c-h_1)^2}{2}\right) & \tau \in (\frac{k}{c}, \frac{3k}{2c}) \text{ and } c - \frac{k}{\tau} \leq h_1 \leq \frac{k}{2\tau} \\ h_1k - \frac{\tau h_1^2}{2} + \delta\left(\frac{k(k+2\tau h_1)}{2\tau}\right) & \tau \in (\frac{3k}{2c}, \infty) \text{ and } h_1 \leq \frac{k}{2\tau}. \end{cases}$$

By the first order conditions, given that the second order conditions are satisfied, we obtain

Table A2: No rent in the second period

τ	h_1	h_2	h_1+h_2	Π_1^U	Π_2^U
$\left(0, \frac{k}{c}\right)$	$\frac{c(2k-c\tau)}{2k}$	$\frac{\tau c^2}{2k}$	c	$\frac{c(2k-c\tau)\left(c\tau(c\tau-2k)+4k^2\right)}{8k^2}$	$\frac{c\left(8k^3-c^3\tau^3\right)}{8k^2}$
$\left(\frac{k}{c}, \frac{3k}{2c}\right)$	$\frac{k}{2\tau}$	$\frac{2c\tau-k}{2\tau}$	c	$\frac{3k^2}{8\tau}$	$\frac{4c\tau(3k-c\tau)-k^2}{8\tau}$
$\left(\frac{3k}{2c}, \infty\right)$	$\frac{k}{2\tau}$	$\frac{k}{\tau}$	$\frac{3k}{2\tau} < c$	$\frac{3k^2}{8\tau}$	$\frac{k^2}{\tau}$

Note that, in this case, the optimum level of h_1 is always set at the "rent bound" (for low τ at $c\left(2k - c\tau\right)/2k$ and for high τ at $k/2\tau$) and not lower than that. This means that U supplies the highest possible technology to D without leaving a rent to it at the second period of the game. Moreover, note that when technology transfer is too costly, that is, τ is high enough the sum of the technology transfer from both periods is not enough to reduce the second period's production cost at zero ($c_2 > 0$). In contrast, when technology is not as costly, the second period's production cost reduces to zero ($c_2 = 0$).

Case 1B: Rent extracted by D in the second period. For h_1 sufficiently high, U leaves a positive rent to D in the second period. Thus, U solves

$$\max_{h_1} PV^{R} = \Pi_1^U + \delta\Pi_2^U$$
$$= \begin{cases} h_1k - \frac{\tau h_1^2}{2} + \delta\left(\frac{(c-h_1)(2k-c\tau+\tau h_1)}{2}\right) & \tau \in (0, \frac{k}{c}) \text{ and } \frac{c(2k-c\tau)}{2k} < h_1 \leq c \\ h_1k - \frac{\tau h_1^2}{2} + \delta\left(\frac{(c-h_1)(2k-c\tau+\tau h_1)}{2}\right) \quad if & \tau \in (\frac{k}{c}, \frac{3k}{2c}) \text{ and } \frac{k}{2\tau} < h_1 \leq c \\ h_1k - \frac{\tau h_1^2}{2} + \delta\left(\frac{k^2}{2\tau}\right) & \tau \in (\frac{3k}{2c}, \infty) \text{ and } \frac{k}{2\tau} < h_1 \leq c - \frac{k}{\tau} \\ h_1k - \frac{\tau h_1^2}{2} + \delta\left(\frac{(c-h_1)(2k-c\tau+\tau h_1)}{2}\right) & \tau \in (\frac{3k}{2c}, \infty) \text{ and } c - \frac{k}{\tau} < h_1 \leq c. \end{cases}$$

By the first order conditions, given that the second order conditions are satisfied, we obtain

Table A3: Rent in the second period

τ	δ	h_1	h_2	h_1+h_2	Π_1^U	Π_2^U
$(0,\frac{k(1-\delta)}{c})$		c	0	c	$\frac{c(2k-c\tau)}{2}$	0
$(\frac{k(1-\delta)}{c},\frac{k}{c})$	$(0,\overline{\delta})$	$\frac{k(1-\delta)+c\tau\delta}{\tau(1+\delta)}$	$\frac{c\tau-k(1-\delta)}{\tau(1+\delta)}$	c	$\frac{k^2(3\delta+1)(1-\delta)+c\tau\delta^2(4k-c\tau)}{2\tau(\delta+1)^2}$	$\frac{(c\tau-k(1-\delta))((3+\delta)k-c\tau)}{2\tau(\delta+1)^2}$
$(\frac{k(1-\delta)}{c},\frac{k}{c})$	$(\overline{\delta},1)$	$\frac{c(2k-c\tau)}{2k}$	$\frac{\tau c^2}{2k}$	c	$\frac{c(2k-c\tau)\left(c\tau(c\tau-2k)+4k^2\right)}{8k^2}$	$\frac{c^2\tau(2k-c\tau)(2k+c\tau)}{8k^2}$
$(\frac{k}{c},\frac{2k}{c})$		$\frac{k(1-\delta)+c\tau\delta}{\tau(1+\delta)}$	$\frac{c\tau-k(1-\delta)}{\tau(1+\delta)}$	c	$\frac{k^2(3\delta+1)(1-\delta)+c\tau\delta^2(4k-c\tau)}{2\tau(\delta+1)^2}$	$\frac{(c\tau-k(1-\delta))((3+\delta)k-c\tau)}{2\tau(\delta+1)^2}$
$(\frac{2k}{c},\infty)$		$\frac{k}{\tau}$	$\frac{k}{\tau}$	$\frac{2k}{\tau}< c$	$\frac{k^2}{2\tau}$	$\frac{k^2}{2\tau}$
$\overline{\delta}\equiv\frac{c^2\tau^2+2k(k-c\tau)}{2k^2-c^2\tau^2}$						

Note that for very low values of the cost parameter τ, technology is transferred at once, meaning that the production cost is reduced at the zero level in the first period ($c_1= 0$). While τ increases, h_1 decreases and for very high τ the sum of the technology transfer from both periods is less than c and the second period's cost is not reduced to zero ($c_2> 0$).

To derive the equilibrium of the whole game, we compare, for all parameter values, the present value of U's profits, when zero rent or positive rent is extracted by D in the second period of the game (PV^{NR} vs. PV^{R}), by using the relevant expressions by Table A2 and A3. We obtain

Table A4: Equilibrium outcome under Vertical Separation							
τ	δ	*equil.*	h_1^{VS}	h_2^{VS}	$h_1^{VS}+h_2^{VS}$	Π_1^U	Π_2^U
$(0,\frac{k(1-\delta)}{c})$	$(0,\delta_1)$	*rent*	c	0	c	$\frac{c(2k-c\tau)}{2}$	0
$(0,\frac{k(1-\delta)}{c})$	$(\delta_1,1)$	*no rent*	$\frac{c(2k-c\tau)}{2k}$	$\frac{\tau c^2}{2k}$	c	$\frac{c(2k-c\tau)\left(c\tau(c\tau-2k)+4k^2\right)}{8k^2}$	$\frac{c\left(8k^3-c^3\tau^3\right)}{8k^2}$
$(\frac{k(1-\delta)}{c},\frac{k}{c})$	$(0,\delta_2)$	*rent*	$\frac{k(1-\delta)+c\tau\delta}{\tau(1+\delta)}$	$\frac{c\tau-k(1-\delta)}{\tau(1+\delta)}$	c	$\frac{k^2(3\delta+1)(1-\delta)+c\tau\delta^2(4k-c\tau)}{2\tau(\delta+1)^2}$	$\frac{(c\tau-k(1-\delta))((3+\delta)k-c\tau)}{2\tau(\delta+1)^2}$
$(\frac{k(1-\delta)}{c},\frac{k}{c})$	$(\delta_2,1)$	*no rent*	$\frac{c(2k-c\tau)}{2k}$	$\frac{\tau c^2}{2k}$	c	$\frac{c(2k-c\tau)\left(c\tau(c\tau-2k)+4k^2\right)}{8k^2}$	$\frac{c\left(8k^3-c^3\tau^3\right)}{8k^2}$
$(\frac{k}{c},\frac{3k}{2c})$	$(0,\delta_3)$	*rent*	$\frac{k(1-\delta)+c\tau\delta}{\tau(1+\delta)}$	$\frac{c\tau-k(1-\delta)}{\tau(1+\delta)}$	c	$\frac{k^2(3\delta+1)(1-\delta)+c\tau\delta^2(4k-c\tau)}{2\tau(\delta+1)^2}$	$\frac{(c\tau-k(1-\delta))((3+\delta)k-c\tau)}{2\tau(\delta+1)^2}$
$(\frac{k}{c},\frac{3k}{2c})$	$(\delta_3,1)$	*no rent*	$\frac{k}{2\tau}$	$\frac{2c\tau-k}{2\tau}$	c	$\frac{3k^2}{8\tau}$	$\frac{4c\tau(3k-c\tau)-k^2}{8\tau}$
$(\frac{3k}{2c},\frac{2k}{c})$	$(0,\delta_4)$	*rent*	$\frac{k(1-\delta)+c\tau\delta}{\tau(1+\delta)}$	$\frac{c\tau-k(1-\delta)}{\tau(1+\delta)}$	c	$\frac{k^2(3\delta+1)(1-\delta)+c\tau\delta^2(4k-c\tau)}{2\tau(\delta+1)^2}$	$\frac{(c\tau-k(1-\delta))((3+\delta)k-c\tau)}{2\tau(\delta+1)^2}$
$(\frac{3k}{2c},\frac{2k}{c})$	$(\delta_4,1)$	*no rent*	$\frac{k}{2\tau}$	$\frac{k}{\tau}$	$\frac{3k}{2\tau}$	$\frac{3k^2}{8\tau}$	$\frac{k^2}{\tau}$
$(\frac{2k}{c},\infty)$	$(0,\frac{1}{4})$	*rent*	$\frac{k}{\tau}$	$\frac{k}{\tau}$	$\frac{2k}{\tau}$	$\frac{k^2}{2\tau}$	$\frac{k^2}{2\tau}$
$(\frac{2k}{c},\infty)$	$(\frac{1}{4},1)$	*no rent*	$\frac{k}{2\tau}$	$\frac{k}{\tau}$	$\frac{3k}{2\tau}$	$\frac{3k^2}{8\tau}$	$\frac{k^2}{\tau}$
$\delta_1\equiv\frac{c\tau(2k-c\tau)}{c^2\tau^2+2k(2k+c\tau)}$, $\delta_2\equiv\frac{2k(k+c\tau)\left(c^2\tau^2+2k(k-c\tau)\right)-c^4\tau^4-2(2k-c\tau)\sqrt{ck^3\tau(2c^2\tau^2+k(4k-3c\tau))}}{c^4\tau^4+4k^3(k-2c\tau)}$							
$\delta_3\equiv\frac{2\sqrt{k^3(5k-2c\tau)}-k(5k-2c\tau)}{(2c\tau-k)(5k-2c\tau)}$, $\delta_4\equiv\frac{4c\tau(4k-c\tau)-19k^2+\sqrt{(4c\tau(c\tau-3k)+13k^2)(4c\tau(c\tau-5k)+29k^2)}}{8k^2}$							