On the Dynamics of Technology Transfer*

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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 type of 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.

Keywords: Technology transfer; Vertical contracts; Hold-up.

JEL Codes: O3; L1; L22; D23

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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 amount 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. An obvious case of technology transfer, that has received much attention in the literature, would be 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 are not fully enforceable. The vertical chains that are created in this way could be also viewed as joint ventures (JV).

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 rate 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.[1] Nevertheless, the literature has not dealt, to the best of our knowledge, with the general issue of modeling and analyzing situations where the downstream oligopoly market structure, the rate and amount 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 the 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 in 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 rate of the technology transferred is less than in the perfect contracting case, i.e. the VI case where the upstream firm is locked with its own downstream firm each period. We find that, for somem 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 the D by reducing the technology transfer in the first period to the level that does not make the D strong enough to threaten stop dealing with U in the future.

[1] We present the related literature in detail in the next section.

In particular, we find that U tends to give rent to the D for low values of the discount factor δ, since future is not valuable enough. Moreover, D tends to extract rent for high values of the technology adoption cost parameter τ, 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.

Related literature Our work is related to three broad literature areas: on technology licensing, on FDI and on vertical contracting. 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). Another issue examined in our model is 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.

The role of FDI in international technology transfer has been studied by Saggi (2002) and more recently 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.

The third 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.[2] 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. 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.

Finally, there are few papers examining the strategic timing of licensing. For example, Lin and Saggi (1999) propose a dynamic model where technology transfer generates cost-lowering spillovers for the competitor, and find that imitation risk may intensify competition. Allain *et al.* (2011) 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. Emeric and Ponce (2011) study the dynamic pricing of knowledge by examining the incentives to imitate rather than innovate. Our research combines the three literatures. 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 basic model. Vertical integration is examined in Section 3. In Section 4, we present the equilibrium analysis under vertical separation, while the equilibrium outcome under vertical separation and its properties are presented separately in Section 5. In Section 6, we study the case where the downstream firms might have different initial production costs across periods. Section 7 discusses other extentions of our basic model, first, the case of different initial costs across firms at the same period and, second, the case of Cournot retail competition. Section 8 concludes.

[2] For a general review, see Motta (2004).

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 is reflected by a quadratic function $C(h_t) = \frac{\tau h_t^2}{2}, \tau \geq 0$. This cost is paid by U that supplies the technology. Assume an inelastic demand function $Q = k$, where the reservation value v of the buyers surpasses the initial production cost c.[3] 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 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. The vertically separated model is studied in Section 5, where U charges a fixed fee F_t when technology h_t is transferred. The game is:

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.[4]

[3] The model with a linear demand function is presented in the Appendix. For expositional simplicity in the main body of the paper we present the inelastic demand case.

[4] Note that U transfers technology to only one firm each period. Downstream firms compete à la Bertrand and

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. Firm D' pays the fee F_2' to U.

The game is solved by backwards induction.

3 Vertical Integration

In this vertical structure, the vertically integrated firms, U and D, maximize their joint profits.[5] We solve the game backwards starting from the second period. Given that in the first period, U has tranferred 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, $p_2^{VI} = c$.[6] Then, the VI chain chooses the level of h_2 by maximizing their joint profit

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

From the first order conditions, we obtain

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

the more cost efficient firm takes the whole demand each period.

[5] 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 both periods.

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

The second order conditions are satisfied ($d\Pi_2^{VI}/dh_2 = -\tau$).[7] Note that the production costs cannot be negative, thus, we have $c_2 = c - h_1 - h_2 \geq 0$ 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, i.e., $h_2 = c - h_1$. Replacing for h_2 into (1), the second period's profit is

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

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

In the first period, D faces the lower cost $c_1 = c - h_1$ compared to the rest downstream firms and, thus the final price is set at cost 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 Lemma.

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*

[7] The case where $h_1 \leq c - \frac{k}{\tau}$ is only valid when $c - \frac{k}{\tau} > 0$, i.e., $\tau > \frac{k}{c}$.

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	$\frac{(k+\delta(2k-c\tau))(k+c\tau\delta)}{2\tau(\delta+1)^2}$	$kc-\frac{(c\tau-k)^2}{2\tau(\delta+1)^2}$
$(\frac{k(2+\delta)}{c},\infty)$	$\frac{k(1+\delta)}{\tau}$	$\frac{k}{\tau}$	$\frac{k(2+\delta)}{\tau}<c$	$\frac{k^2\left(1-\delta^2\right)}{2\tau}$	$\frac{k^2(2\delta+3)}{2\tau}$

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 Equilibrium analysis under Vertical Separation

We present now the analysis under vertical separation, where U charges a fixed fee F_t when it transfers technology h_t. We proceed backwards to solve for the subgame perfect equilibrium.

4.1 Second period

Stage 2.2 Final prices in the second period

In this stage the downstream firms compete by setting the final price p_2. However, this decision depends on the second period's procuction 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. The profit function for the downstream firms is

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

We present each case separately.

Case 1: D is supplied h_2

Firm D has accepted the offer (h_2, F_2) made by U at Stage 2.1. Thus, 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. The profit function for D is

$$\Pi_2^D = (p_2 - c + h_1 + h_2)k - F_2 = (h_1 + h_2)k - F_2. \tag{2}$$

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 technology h_2'

Firm D has rejected the offer (h_2, F_2) made by U and does not have any 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. 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. Under this constraint and due to the Bertrand competition downstream, the final price is set at $c - h_1$. D' obtains the whole demand and gets profits

$$\Pi_2^{D'} = (p_2 - c + h_2')k - F_2' = (h_2' - h_1)k - F_2'. \tag{3}$$

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. D produces alone, without a further cost reduction, but still being the more cost efficient firm with cost equal to $c - h_1$, while the other firms have the initial production cost c. Thus, the price p_2 is set st c. The profit function for D is

$$\Pi_2^D = (p_2 - c + h_1)k = h_1 k, \tag{4}$$

with all other downstream profits being zero.

Stage 2.1 Contract terms in the second period

In this stage, U sets the contracts terms; the level of technology transfer and the payment for the technology tranfered in the second period. 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, i.e., obtains a positive profit or not. The profit function for firm U is

$$\Pi_2^U = \begin{cases} F_2 - \frac{\tau h_2^2}{2} & if \quad h_2 \text{ is tranferred} \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$

We present the various cases and prove that U prefers to transfer technology to the same downstream firm D that supplied in the first period.

Case 1A: D is supplied h_2 and extracts no rent

Firm D accepts the take-it-or-leave-it offer (h_2, F_2) made by U. This holds when D does not obtain lower profits than the profits obtained by rejecting the offer and producing alone.[8] Here, firm U could potentially serve another downstream firm D', thus, if D would have rejected the offer, it would have obtained zero profits. Thus, D accepts any offer that gives non-negative profits. In addition, U would potentially serve D' when U's profits are non-negative ($\Pi_2^U(h_2', F_2') \geq 0$). This is a necessary condition for this case to hold. Since U has the bargaining power, it offers a fixed fee F_2 to extract all profits by firm D. By (2), we have $\Pi_2^D = 0$ when

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

Replacing for F_2 into (5), we have

$$\Pi_2^U(h_2, F_2) = (h_1 + h_2)k - \frac{\tau h_2^2}{2}. \tag{6}$$

Firm 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 in the vertical integration case, the production costs 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, i.e., $h_2 = c - h_1$. Replacing for h_2 into (6), we obtain

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

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

where $\Pi_2^U > 0$.[9,10] 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

Firm D accepts the take-it-or-leave-it offer (h_2, F_2) made by U. This holds when D does not obtain lower profits than the profits obtained by rejecting the offer and producing alone. Firm U could not potentially serve another firm D', something that holds for $\Pi_2^U(h_2', F_2') < 0$. If D would have rejected the offer, it would obtain positive profits equal to $h_1 k$, as calculated at Stage 2.2. Thus, the offer made by U leaves a positive rent equal to $h_1 k$ to firm D

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

By replacing this into (2), we have

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

Moreover, U determines h_2 by maximizing

$$\Pi_2^U(h_2, F_2) = h_2 k - \frac{\tau h_2^2}{2}. \tag{7}$$

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 (7), 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 $\Pi_2^U(h_2', F_2') < 0$.

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

[10] The case where $h_1 \leq c - \frac{k}{\tau}$ is only valid when $\tau > \frac{k}{c}$.

Case 2A: D' is supplied h_2'

Firm D rejects the offer (h_2, F_2) and U makes an offer (h_2', F_2') to firm D'. Firm D' accepts the offer when it obtains non-negative profits, since D' has not dealt before with U. In addition, this case holds when the U's profits by dealing with firm D' are non-negative, i.e., $\Pi_2^U(h_2', F_2') \geq 0$. With its offer, U extracts all profits by D' through the fixed fee F_2'. By (3), we have $\Pi_2^{D'} = 0$ when

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

Thus, U sets h_2' to maximize its profits

$$\Pi_2^U\left(h_2', F_2'\right) = \left(h_2' - h_1\right) k - \frac{\tau (h_2')^2}{2}. \tag{8}$$

From the first order conditions, we obtain

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

Of course, we need $h_2' > h_1$, otherwise D' obtains zero demand. Replacing for h_2' into (8), 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, $\Pi_2^U(h_2', F_2') \geq 0$, 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 $\Pi_2^U(h_2', F_2') \geq 0$ and $h_2' > h_1$ is satisfied. We have determined the "rent bound" for h_1, either $k/2\tau$ when $\tau \geq k/c$ or $c\,(2k - c\tau)\,/2k$ 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, firm D would not extract a positive rent if it has accepted the offer by U.

Case 2B: No downstream firm is supplied h_2

Firm 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 that make $\Pi_2^U(h_2', F_2')$ negative, i.e., for h_1 higher than the "rent bound". Firm U does not operate in the second period and firm D enjoys positive profits equal to $h_1 k$.

Therefore, we conclude that Case 1A and 2A hold when $\Pi_2^U(h_2', F_2') \geq 0$, equivalently $h_1 \leq k/2\tau$ for $\tau \geq k/c$ or $h_1 \leq c(2k - c\tau)/2k$ 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 2, we summarize these results.

Table 2: 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

Thus far, we have determined the contract terms for the various values of the technology transfer h_1 already supplied in the first period to firm D. However, the equilibrium in Stage 2.1 remains to be derived. We now determine U's equilibrium strategy. Is it more profitable for firm 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 Case 1A to 2A and between Case 1B to 2B by taking the relevant expressions from Table 2, we find that

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

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. Intuitively, firm U has already invested in firm 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.

4.2 First period

Stage 1.2 Final prices in the first period

Given that U has transferred technology h_1 to firm 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

$$\Pi_1^D = (p_1 - c + h_1)k - F_1 = h_1 k - F_1, \tag{9}$$

and all other downstream firms obtain zero demand and profits.

Stage 1.1 Contract terms in the first period

In this stage, firm U offers a contract (h_1, F_1) to the downstream firms. However, all downstream firms are initially cost symmetric and would accept the offer when obtaining non-negative profits, firm U chooses randomly to supply h_1 to firm D. Firm 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. By (9), we have $\Pi_1^D = 0$ for

$$F_1 = h_1 k.$$

Firm 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. As shown before when h_1 is low enough, U extracts all profits by D without leaving any positive rent to it. 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 taken by Table 2, depending on whether D extracts rent or not.

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

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

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

Table 3: 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	$\frac{3k^2}{8\tau}$	$\frac{4c\tau(3k-c\tau)-k^2}{8\tau}$
$\left(\frac{3k}{2c}, \infty\right)$	$\frac{k}{2\tau}$	$\frac{k}{\tau}$	$\frac{3k}{2\tau} < c$	$\frac{3k^2}{8\tau}$	$\frac{k^2}{\tau}$

The present value of the profits is derived by replacing Π_1^U and Π_2^U into $PV^{NR} = \Pi_1^U + \delta \Pi_2^U$. Note that, in this case, the optimum level of h_1 is always set at the "rent bound" (for low τ at $c(2k - c\tau)/2k$ 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, i.e., 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, firm U leaves a positive rent to D in the second period. Thus, U solves

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

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

Table 4: 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	$\frac{k^2(3\delta+1)(1-\delta)+c\tau\delta^2(4k-c\tau)}{2\tau(\delta+1)^2}$	$\frac{(c\tau-k(1-\delta))((3+\delta)k-c\tau)}{2\tau(\delta+1)^2}$
$(\frac{2k}{c},\infty)$		$\frac{k}{\tau}$	$\frac{k}{\tau}$	$\frac{2k}{\tau}< c$	$\frac{k^2}{2\tau}$	$\frac{k^2}{2\tau}$
$\overline{\delta}\equiv\frac{c^2\tau^2+2k(k-c\tau)}{2k^2-c^2\tau^2}$						

The present value of the profits is derived by replacing Π_1^U and Π_2^U into $PV^R = \Pi_1^U + \delta\Pi_2^U$. 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 tecnology transfer from both periods is less than c and the second period's cost is not reduced to zero ($c_2> 0$).

Now remains to determine the equilibrium level of h_1 between the two possible cases. 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. Nevetheless, 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. The equilibrium level of technology transfer h_1 is presented in the next section.

5 Equilibrium outcome under Vertical Separation

5.1 Rent vs. No Rent

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 3 and 4. Therefore, for each value of τ and δ, we find the h_1 that maximizes the present value of U's profits. From this comparison, we have

Proposition 2 *The equilibrium outcome, for all parameter values, under vertical separation is presented in Table 5.*

Table 5: 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*	$\frac{k}{2\tau}$	$\frac{k}{\tau}$	$\frac{3k}{2\tau}< c$	$\frac{3k^2}{8\tau}$	$\frac{k^2}{\tau}$
$(\frac{2k}{c},\infty)$	$(0,\frac{1}{4})$	*rent*	$\frac{k}{\tau}$	$\frac{k}{\tau}$	$\frac{2k}{\tau}< c$	$\frac{k^2}{2\tau}$	$\frac{k^2}{2\tau}$
$(\frac{2k}{c},\infty)$	$(\frac{1}{4},1)$	*no rent*	$\frac{k}{2\tau}$	$\frac{k}{\tau}$	$\frac{3k}{2\tau}< c$	$\frac{3k^2}{8\tau}$	$\frac{k^2}{\tau}$
$\delta_1\equiv\frac{c\tau(2k-c\tau)}{c^2\tau^2+2k(2k+c\tau)}\delta_1\equiv\frac{c\tau(2k-c\tau)}{c^2\tau^2+2k(2k+c\tau)},\delta_2\equiv\frac{2k(k+c\tau)\left(c^2\tau^2+2k(k-c\tau)\right)-c^4\tau^4-2(2k-c\tau)\sqrt{ck^3\tau(2c^2\tau^2+k(4k-3c\tau))}}{c^4\tau^4+4k^3(k-2c\tau)}$							
$\delta_3\equiv\frac{2\sqrt{k^3(5k-2c\tau)}-k(5k-2c\tau)}{(2c\tau-k)(5k-2c\tau)},\delta_4\equiv\frac{4c\tau(4k-c\tau)-19k^2+\sqrt{(4c\tau(c\tau-3k)+13k^2)(4c\tau(c\tau-5k)+29k^2)}}{8k^2}$							

Note 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 ($c_2>0$). Moreover, note that rent is extracted by D in the second period for low values of the discount factor δ, as future is not very valuable.

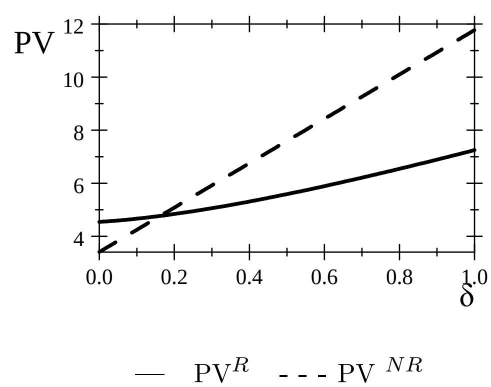
5.2 Numerical example

We additionally present some numerical examples to illustrate the equilibrium outcome. For example, we take the case where $\tau \in (\frac{k}{c}, \frac{3k}{2c})$. By Table 3 and Table 4, we derive the present value of U's profits when zero rent or positive rent is extracted by D, respectively.

$$PV = \begin{cases} \frac{k^2(3\delta+1)(1-\delta)+c\tau\delta^2(4k-c\tau)}{2\tau(\delta+1)^2} + \delta\frac{(c\tau-k(1-\delta))((3+\delta)k-c\tau)}{2\tau(\delta+1)^2} & if \quad \text{rent is extracted} \\ \frac{3k^2}{8\tau} + \delta\frac{4c\tau(3k-c\tau)-k^2}{8\tau} & if \quad \text{no rent is extracted.} \end{cases}$$

Further, we set $k = 10$, $c = 1$, $\tau = 11$ and plot, for all values of the discount factor δ, the present values.

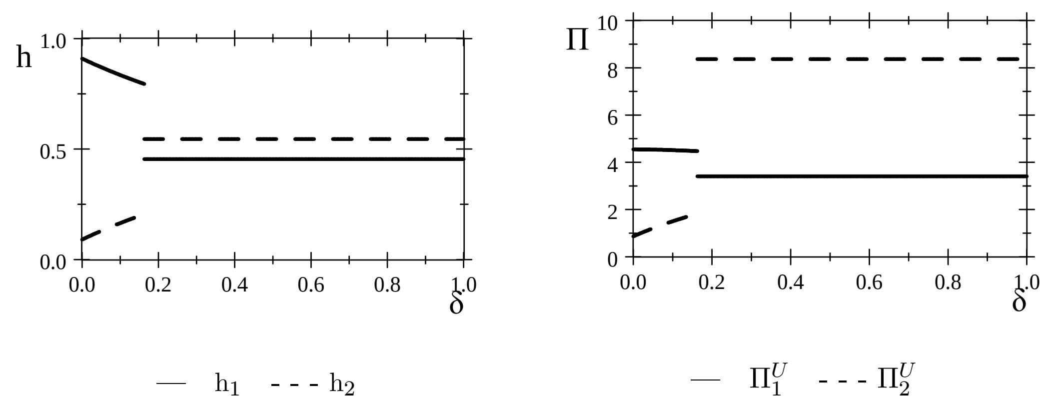
Figure 1: PV of profits for every δ and $k = 10, c = 1, \tau = 11$



When δ is low enough (lower than δ_3= 0.163), U cares less about the future, thus, it prefers to transfer a high level of technology to D in the first period to enjoy low cost in this period, something that leads to rent extraction by D in the second period of the game. However, for higher values of δ, U prefers not to give rent to D in the second period by reducing the level of technology transferred to D in the first period. Thus, U reduces the cost advantage of downstream firm D compared to the other downstream firms that produce at the initial cost in the subsequent period.

Below, we plot the equilibrium levels of the technology transfer and the profit for both periods.

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



Note that for these parameter values, the total level of technology trasfer 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.

In Table 6, we provide some additional numerical examples. We can further infer that when τ is high, U tends to give rent to D, since it is relatively costly to transfer technology in the second period of the game to a new downstream firm D'. However, when δ increases, it becomes less probable that U gives rent to D. As δ increases, the technology transfer in the first period tends to decrease.

Table 6: Numerical examples for various τ, δ and $k = 10,\ c = 1$

τ	δ	equil.	h_1	h_2	h_1+h_2	Π_1^U	Π_2^U	τ	δ	equil.	h_1	h_2	h_1+h_2	Π_1^U	Π_2^U
0.1	0.1	*no rent*	0.995	0.005	1	9.9005	10	0.1	0.2	*no rent*	0.995	0.005	1	9.9005	10
1	0.1	*no rent*	0.95	0.05	1	9.0488	9.9988	1	0.2	*no rent*	0.95	0.05	1	9.0488	9.9988
5	0.1	*rent*	1	0	1	7.5	0	5	0.2	*no rent*	0.75	0.25	1	6.0938	9.8438
9	0.1	*rent*	1	0	1	5.5	0	9	0.2	*no rent*	0.55	0.45	1	4.1388	9.0888
16	0.1	*rent*	0.60227	0.39773	1	3.1209	2.7118	16	0.2	*rent*	0.58333	0.41667	1	3.1111	2.7778
28	0.1	*rent*	0.35714	0.35714	0.71429	1.7857	1.7857	28	0.2	*rent*	0.35714	0.35714	0.71429	1.7857	1.7857
50	0.1	*rent*	0.2	0.2	0.4	1	1	50	0.2	*rent*	0.2	0.2	0.4	1	1
τ	δ	equil.	h_1	h_2	h_1+h_2	Π_1^U	Π_2^U	τ	δ	equil.	h_1	h_2	h_1+h_2	Π_1^U	Π_2^U
0.1	0.5	*no rent*	0.995	0.005	1	9.9005	10	0.1	0.9	*no rent*	0.995	0.005	1	9.9005	10
1	0.5	*no rent*	0.95	0.05	1	9.0488	9.9988	1	0.9	*no rent*	0.95	0.05	1	9.0488	9.9988
5	0.5	*no rent*	0.75	0.25	1	6.0938	9.8438	5	0.9	*no rent*	0.75	0.25	1	6.0938	9.8438
9	0.5	*no rent*	0.55	0.45	1	4.1388	9.0888	9	0.9	*no rent*	0.55	0.45	1	4.1388	9.0888
16	0.5	*no rent*	0.3125	0.625	0.9375	2.3438	6.25	16	0.9	*no rent*	0.3125	0.625	0.9375	2.3438	6.25
28	0.5	*no rent*	0.17857	0.35714	0.53571	1.3393	3.5714	28	0.9	*no rent*	0.17857	0.35714	0.53571	1.3393	3.5714
50	0.5	*no rent*	0.1	0.2	0.3	0.75	2	50	0.9	*no rent*	0.1	0.2	0.3	0.75	2

5.3 Equilibrium properties

We discuss now the properties of the equilibrium we have derived. First, we compare our findings under vertical separation (VS) to the vertical integration (VI) case. Then we discuss the effect of the various parameters on shaping the equilibrium outcome.

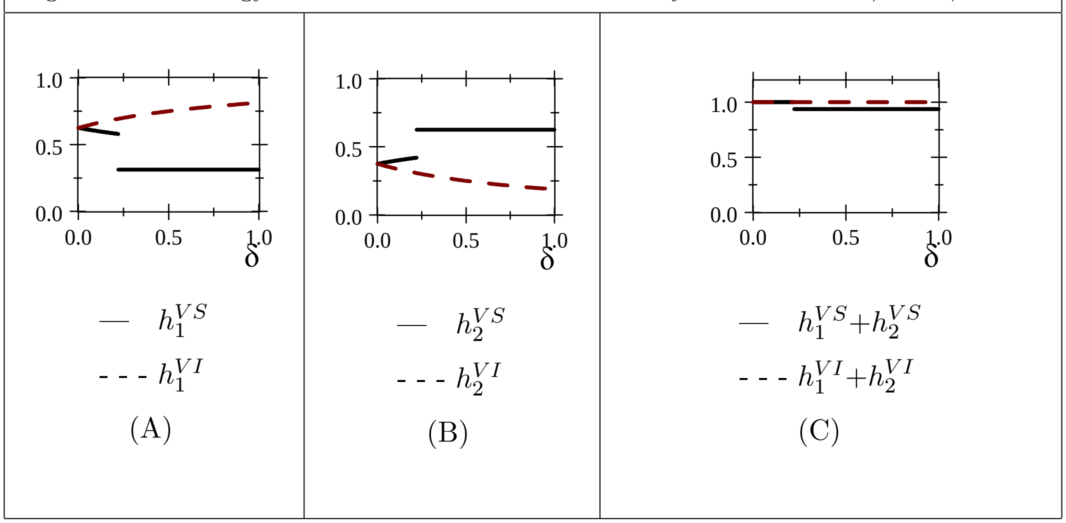
Comparison to the VI case. We contrast our results under VS to the results under VI. By direct comparison of Proposition 1 to Proposition 2, we find that

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* $h_1^{VI} + h_2^{VI} \geq h_1^{VS} + h_2^{VS}$.

For the first period, the level of technology transfer under vertical separation h_1^{VS} is never higher than in the vertical integration benchmark ($h_1^{VI} \geq h_1^{VS}$). It is either lower or equal to the technology transfer of the first period under VI. Under VI, firm U is vertically integrated with firm D. There is no threat that firm D will stop dealing with firm U in the second period of the game, thus, rent is never given within the vertical integrated chain and the incentives of U to reduce the technology transfer in the first period are reduced. Under VS, firm U tends to reduce h_1, compared to the VI case, in an effort to lower the rent paid to firm 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. On the one hand, U decreases or avoids the future rent paid, but, on the other hand, sacrifies some short-rum profits due to a smaller cost reduction, i.e., 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 at the level of the "rent bound".

In Figure 3 we give a numerical example for 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 vertically integrated retailer, 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 firm 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, i.e. 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 is shifted towards the second period under 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} and hold-up issues arise.

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. 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 ($h_1^{VS} + h_2^{VS} < c$).

The dicount factor and the cost of technology transfer. By Lemma 1, we have that, in the equilibrium under VS, U sells technology to a single and the same downstream firm D each period. The vertical chain is stable and the U invests in a single downstream firm. However, under some parameter values, U has to pay a rent at D to make D accept its offer and continue dealing with it in the second period of the game. By Table 5, we conclude that

Proposition 4 *Under vertical separation, the upstream firm U tends to give rent to the downstream firm D for relatively low values of the discount factor δ and relatively high values of the technology cost parameter τ.*

From the discussion above, we can conclude that 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 $h_1 + h_2 < c$, i.e., when τ is sufficiently high ($\tau > 3k/2c$) and the cost of production is eventually not eliminated, U prefers to give a rent when $\delta < 0.25$. Moreover, for a given level of δ, U tends to give rent to D when the cost parameter τ is high enough. When τ is low, U can easily transfer a high level of technology to another downstream firm D' in the second period if the initial downstream firm D stops dealing with it. Thus, for low τ rent cannot be extracted by D.

6 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 costs of each downstream firm across periods. Let the initial production cost 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 and also publicly known ($c_L < c_H$). Think of the case where there are random and exogenous 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.[11] 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, one of the low cost downstream firms, say D, will be chosen by the U to become a licensee. It is interesting to examine whether D will remain licensee in the second period and what will be the equilibrium level and pace of technology transfer.

Note that here the vertical integration case, where U is locked with his vertically integrated partner forever, is no longer equivalent to perfect contracting (meaning that firm U can sign a long-run contract to stay with the same D each period). Now, U might prefer in the second period to stop dealing with the first period's licensee D, if D draws a high cost (that is, has a cost-increasing shock). Therefore, in contrast to the basic model, a potential long-run contract where U deals with the same downstream firm each period might not be an equilibrium outcome.[12] Under vertical integration, firm U is not necessarily in a better position compared to the vertical separation case. Firm 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 unfavorable cost draw of his own downstream firm, 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 $1-\rho$.

On the other hand, under vertical separation, U can stop dealing with the initial licensee D when it has become less efficient than the other firms in the pool, that is, if $c_H - h_1 < c_L$. This is clearly a benefit for U. However, by being vertically separated, the U's choise of h_1 reflects the need to reduce the D's bargaining power, so that the rent given from U to D in the second period, in

[11] 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 Section (7), we discuss a modification of the basic model, where only one downstream firms has a low (high) initial cost compared to all other downstream firms that have high (low) initial costs - but there is no uncertainty, so each downstream firm has the same cost each period.

[12] Note that in our basic model, in equilibrium, U is transferring technology to the same downstream firm in both periods. So it is equivalent to signing a long-run (two-period) contract with a single downstream firm.

case they keep dealing, would not be too large. Therefore, both h_1 and PV of profits are expected to vary for different parameter values, perhaps sometimes being larger under VI and sometimes under VS.

(To be completed)

6.1 Vertical Integration

Let the vertical integrated chain start with a low cost downstream firm D 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 initial cost of the VI partner D continues to be c_L, i.e. the cost without the technology tranfer, the results are similar to our basic model (now $c_2^{VI} = c_L - h_1 - h_2$), since D is the more cost efficient firm in the second period. 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[13]

$$h_2^{VI-LOW} = \begin{cases} \frac{k}{\tau} & if \quad 0 < h_1 \leq c_L - \frac{k}{\tau} \\ c_L - h_1 & if \quad c_L - \frac{k}{\tau} < h_1 \leq c_L, \end{cases}$$

$$\Pi_2^{VI-LOW} = \begin{cases} \frac{k(k+2\tau h_1)}{2\tau} & if \quad 0 < h_1 \leq c_L - \frac{k}{\tau} \\ \frac{2kc_L - \tau(c_L - h_1)^2}{2} > 0 & if \quad c_L - \frac{k}{\tau} < h_1 \leq c_L. \end{cases} \tag{10}$$

However, if the cost drawn to the VI partner D is c_H, the optimal technology transfer changes. The VI chain has $c_2^{VI} = c_H - h_1 - h_2$ and D is the more cost efficient firm and serves the market, if and only if $c_2^{VI} \leq c_L$ or, by rewritting, $h_2 \geq (c_H - c_L) - h_1$. The technology transfer should be high enough to cover the increase in the initial production cost, otherwise the VI chain cannot have positive demand. Also, costs cannot be negative, thus, $c_2^{VI} \geq 0$. Firms compete in the goods market and set a price $p_2^{VI} = c_L$. The VI chain's profits are

$$\Pi_2^{VI-HIGH} = \begin{cases} 0 & if \quad h_2 < (c_H - c_L) - h_1 \\ (c_L - c_H + h_1 + h_2)k - \frac{\tau h_2^2}{2} & if \quad (c_H - c_L) - h_1 \leq h_2 \leq c_H - h_1. \end{cases} \tag{11}$$

[13] Note that the case where $h_1 \leq c_L - \frac{k}{\tau}$, is only valid when $c_L - \frac{k}{\tau} > 0$, i.e., $\tau > \frac{k}{c_L}$.

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 given that (11) is concave in h_2, we obtain

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

Replacing for h_2 into (11), we obtain the second period's profts for the VI chain[14]

$$\Pi_2^{VI-HIGH} = \begin{cases} 0 & h_1 \leq (c_H - c_L) - \frac{k}{\tau} \\ (c_L - c_H + h_1 + \frac{k}{\tau})k - \frac{k^2}{2\tau} \quad if & (c_H - c_L) - \frac{k}{\tau} < h_1 \leq c_H - \frac{k}{\tau} \\ c_L k - \frac{\tau(c_H - h_1)^2}{2} & c_H - \frac{k}{\tau} < h_1 \leq c_L. \end{cases} \tag{12}$$

When the difference in the costs drawn at the second period $(c_H - c_L)$ is high enough and h_1 is low enough, then the VI chain cannot obtain positive demand. However, for intermediate and high levels of h_1, the VI chain obtains the whole demand and all other downstream firms obtain zero profits.

In the first period, the VI chain faces an initial cost c_L and becomes the more cost efficient firm downstream 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 (10) and (12), respectively. For $c_H > 2c_L$ we have

$$PV^{VI} = \begin{cases} h_1 k - \frac{\tau h_1^2}{2} + \delta\rho \frac{k(k+2\tau h_1)}{2\tau} & h_1 < c_L - \frac{k}{\tau} \\ h_1 k - \frac{\tau h_1^2}{2} + \delta\rho \frac{2kc_L - \tau(c_L - h_1)^2}{2} \quad if & c_L - \frac{k}{\tau} < h_1 < (c_H - c_L) - \frac{k}{\tau} \\ h_1 k - \frac{\tau h_1^2}{2} + \delta \left(\rho \frac{2kc_L - \tau(c_L - h_1)^2}{2} + (1-\rho)\left((c_L - c_H + h_1 + \frac{k}{\tau})k - \frac{k^2}{2\tau} \right) \right) & (c_H - c_L) - \frac{k}{\tau} < h_1 \leq c_H - \frac{k}{\tau} \\ h_1 k - \frac{\tau h_1^2}{2} + \delta \left(\rho \frac{2kc_L - \tau(c_L - h_1)^2}{2} + (1-\rho)\left(c_L k - \frac{\tau(c_H - h_1)^2}{2} \right) \right) & c_H - \frac{k}{\tau} < h_1 \leq c_L, \end{cases}$$

[14]Note that the case where $h_1 \leq (c_H - c_L) - \frac{k}{\tau}$, is only valid when $c_L - \frac{k}{\tau} > 0$, i.e., $\tau > \frac{k}{c_H - c_L}$. For these values of τ we also have $c_H - \frac{k}{\tau} > 0$.

while for $c_H < 2c_L$

$$PV^{VI}=\begin{cases} h_1k-\frac{\tau h_1^2}{2}+\delta\rho\frac{k(k+2\tau h_1)}{2\tau} & h_1< (c_H-c_L)-\frac{k}{\tau} \\ h_1k-\frac{\tau h_1^2}{2}+\delta\left(\rho\frac{k(k+2\tau h_1)}{2\tau}+(1-\rho)\left((c_L-c_H+h_1+\frac{k}{\tau})k-\frac{k^2}{2\tau}\right)\right) & if \quad (c_H-c_L)-\frac{k}{\tau}< h_1< c_L-\frac{k}{\tau} \\ h_1k-\frac{\tau h_1^2}{2}+\delta\left(\rho\frac{2kc_L-\tau(c_L-h_1)^2}{2}+(1-\rho)\left((c_L-c_H+h_1+\frac{k}{\tau})k-\frac{k^2}{2\tau}\right)\right) & c_L-\frac{k}{\tau}< h_1\leq c_H-\frac{k}{\tau} \\ h_1k-\frac{\tau h_1^2}{2}+\delta\left(\rho\frac{2kc_L-\tau(c_L-h_1)^2}{2}+(1-\rho)\left(c_Lk-\frac{\tau(c_H-h_1)^2}{2}\right)\right) & c_H-\frac{k}{\tau}< h_1\leq c_L. \end{cases}$$

The VI chain maximizes its present value of profits with respect to h_1. By the first order conditions, and given the constraints, we obtain the optimal h_1^* and the maximum PV of profits for various parameter values. The lower is τ and the higher is δ, the greater transfer h_1^* for VI chain is expected. Also, the result depends on how large is the negative shock to cost, i.e. the relative sizes of c_L and c_H.

For simplicity, we assume that $c_H = 2c_L$.[15] In this case, the equilibrium aoutcome is given by the following table.

Table 7: Asymmetric costs across time periods-Candidate equilibrium outcome under V.I.

τ	h_1^{VI}	$branch$	h_2^{VI-LOW}	$h_2^{VI-HIGH}$
$(0,\frac{k(2+\delta)}{c_L(2+\delta\rho)})$	c_L	$h_1> 2c_L-\frac{k}{\tau}$	0	c_L
$(\frac{k(2+\delta)}{c_L(2+\delta\rho)},\frac{k(1+\delta-\delta\rho)}{c_L})$	c_L	$c_L-\frac{k}{\tau}< h_1\leq 2c_L-\frac{k}{\tau}$	0	$\frac{k}{\tau}$
$(\frac{k(1+\delta-\delta\rho)}{c_L},\frac{k(2+\delta)}{c_L})$	$\frac{k+k\delta-k\delta\rho+\tau\delta\rho c_L}{\tau+\tau\delta\rho}$	$c_L-\frac{k}{\tau}< h_1\leq 2c_L-\frac{k}{\tau}$	$\frac{-(k+k\delta-\tau c_L-k\delta\rho)}{\tau+\tau\delta\rho}$	$\frac{k}{\tau}$
$(\frac{k(2+\delta)}{c_L},\infty)$	$\frac{k(1+\delta\rho)}{\tau}$	$h_1< c_L-\frac{k}{\tau}$	$\frac{k}{\tau}$	not selling

If $h_1^* > c_L$, the transter is limited by c_L as there is no negative cost. We can compare this case to the V.I. case with stable (low) cost across periods, i.e. when there is no possibility of negative shock:

τ	h_1	$branch$	h_2
$(0,\frac{k}{c})$	c	$h_1= c$	0
$(\frac{k}{c},\frac{k(2+\delta)}{c})$	$\frac{k+c\tau\delta}{\tau(\delta+1)}$	$c-\frac{k}{\tau}< h_1< c$	$\frac{c\tau-k}{\tau(\delta+1)}$
$(\frac{k(2+\delta)}{c},\infty)$	$\frac{k(1+\delta)}{\tau}$	$h_1\leq c-\frac{k}{\tau}$	$\frac{k}{\tau}$

Set $c = c_L$ for comparison. In the case when negative shocks are possible, there is a decrease in h_1 for period 1. E.g. $\frac{k(1+\delta-\delta\rho)}{c_L} < \frac{k}{c}$ hence for the region $\tau\in(\frac{k(1+\delta-\delta\rho)}{c_L},\frac{k}{c})$ we have $\frac{k+k\delta-k\delta\rho+\tau\delta\rho c_L}{\tau+\tau\delta\rho} <$

[15] The general case where $c_H > c_L$ is available by the authors upon request.

c - the incentive to transfer technology has decreased. In a similar way, for $\tau \in (\frac{k(2+\delta)}{c_L}, \infty)$ we have that $\frac{k(1+\delta\rho)}{\tau} < \frac{k(1+\delta)}{\tau}$, therefore transfer h_1 is lower. Higher expected cost lowers the expected PV and thus lowers the technology transfer in period 1.

On the other hand, we would also expect that the upstream firm might try to insure itself against the possibility of a negative shock, investing more than would be optimal otherwise, since in VI it is not allowed to break the contract with its licensee and thus it risks to stay out of the market in period 2. This need to be checked for other values of c_L and c_H .

7 Other extentions

We discuss here two extentions of our basic model. First, the model where there are different initial costs across the downstream firms. Second, the model where firms compete in quantities.

Different initial costs across downstream firms Consider the case where the downstream firms are not homogeneous with respect to their initial costs, but there are different initial costs across the downstream firms (without any uncertainty - each firm faces the same initial cost each period). There are three possible settings that differ qualitatively. In the first setting, there are many firms with high initial cost c_H and only one with low initial cost c_L, thus, there is a single more efficient firm in the pool when technology is not tranferred. In the second setting, there are many firms with low initial cost c_L and only one with high c_H, thus, there is a single less efficient firm in the pool when technology is not tranferred. Finally, in the third setting, there are many (at least two) initially high cost firms and many (at least two) initially low cost firms. However, the latter setting is equivalent to our basic model where all firms face the same initial cost c, since this is a two-period model.

It is interesting to examine whether firm U, in the first and the second setting, will chose to transfer technology in the first period to the most efficient firm and not the least. 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 want to keep in store a potential efficient licensee to discipline the actual licensee and to prevent the latter from extracting a large rent in the second period. We expect that this will not be the case in the second setting where there are many firms with low initial costs, but it might be the case in the first setting where there is initially a single more efficient firm.

(To be completed)

Cournot competition Having analysed the Bertrand competition framework, it would also be of interest to consider Cournot competition downstream. The principal difference in the Cournot set-up is that more than one firm may produce and sell, despite the cost asymmetries between the downstream firms. This allows for additional strategic thinking by U, which might attempt to invest in two (or more) downstream firms than in a single one. The reasoning is that U may want to create a competitive threat for the second period to reduce the bargaining power of its licensees, so that they would not receive a rent from U.

(To be completed)

8 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 that 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, while 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, comparing to the vertical integration 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 vertical integration case. Hold-up issues arise. We find that, for some parameter values, the downstream firm that deals with the upstream firm, receives a rent in the second period of the game. This is due to the bargaining power that the downstream firm acquires, since it faces a lower production cost compared to the other downstream firms as it has paid for technology transfer in the first period. We obtain that the upstream firm tends to give rent to the downstream firm for relatively low values of the discount factor δ and relatively high values of the technology cost parameter τ, since future is not very important and it is very costly for the upstream firm to switch to another downstream firm in the second period. Overall, competition downstream is not able to resolve the hold-up problem created by the imperfect intellectual property rights.

Considering a number of extensions will offer additional insights into the problem. In possible extensions of this paper, we intend to examine the case of different parameter values of τ between the two periods, to investigate the possibility of the upstream firm to make an agreement with the initially less cost efficient firm in an effort to reduce the probability to give a rent in the future. Another interesting extension would be the introduction of uncertain production costs in our basic model. In that case, it is no longer clear that the upstream firm would want to contract with the same firm each period.

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Appendix: Linear demand function

Let us now depart from the inelastic demand function model by assuming a linear demand function $Q_t = a - p_t$, with $a > c$. The remaining assumptions of the basic model remain the same. Similarly to the analysis in the main body of the paper, we present first the Vertical Integration case and then the Vertical Separation case.

A1. Vertical Integration with linear demand function

The vertically integrated firms U-D maximize their joint profits. U does not transfer technology to another downstream firm since downstream firms compete in prices in the final market. Also, D does not break away to operate as a separate firm. We solve the game backwards. In period 2, the vertically integrated chain maximizes its chain profits

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

Since D is the only downstream firm with a reduced marginal cost $c_2 = c - h_1 - h_2$, it will set the price at the level that is slightly below the production cost of the competitors to take the whole demand, i.e., $p_2^{VI} = c - \varepsilon$, where $\epsilon \to 0$. However, this holds when the monopoly price ($p^M = \frac{a+c_2}{2}$) is higher than the cost of the competitors c. If the technology transfer is so high that the monopoly price is lower than the cost of the competitiors c ($\frac{a+c-h_1-h_2}{2} < c$), then profits are maximized at the monopoly price in period 2. Moreover, the total technology transfer cannot be higher than the initial marginal cost ($h_1+h_2 \leq c$), no negative marginal costs exist. Thus, from now on, we assume for simplicity that a is sufficiently high ($a \geq 2c$), which certifies that the monopoly price is always higher than the initial production cost c. Therefore

$$\Pi_2^{VI} = (h_1 + h_2)(a-c) - \frac{\tau h_2^2}{2}.$$

Then h_2 is set to maximize Π_2^{VI}. From the first order conditions, we obtain

$$h_2^{VI} = \frac{a-c}{\tau}.$$

The second order conditions are satisfied. The profits from period 2 are

$$\Pi_2^{VI} = h_1(a-c) + \frac{(a-c)^2}{2\tau}.$$

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

In the first period, the vertically integrated chain chooses a price p_1 to maximize the present value of the joint profits (PV^{VI})

$$PV^{VI} = \Pi_1^{VI} + \delta\Pi_2^{VI} = (p_1 - c + h_1)(a - p_1) - \frac{\tau h_1^2}{2} + \delta\Pi_2^{VI}$$

Again firm D has a cost advantage and sets $p_1^{VI} = c$ and obtains the whole demand. Now, we have

$$PV^{VI} = h_1(a-c) - \frac{\tau h_1^2}{2} + \delta\left(h_1(a-c) + \frac{(a-c)^2}{2\tau}\right).$$

The optimum h_1 is

$$h_1^{VI} = \frac{(1+\delta)(a-c)}{\tau}.$$

Lemma A1. *Under vertical integration the equilibrium prices, profits and technology transfer are* $p_1^{VI} = p_2^{VI} = c, \Pi_1^{VI} = \frac{(3\delta+\delta^2+1)(a-c)^2}{2\tau}, \Pi_2^{VI} = \frac{(2\delta+3)(a-c)^2}{2\tau}, h_1^{VI} = \frac{(1+\delta)(a-c)}{\tau}, h_2^{VI} = \frac{a-c}{\tau}$.

A2. Vertical Separation with linear demand function

Now assume that firms are vertically separated and fixed fees are charged by the U when technology is transferred. Again we proceed backwards.

Period 2

Similarly to the inelastic demand model, we solve for the downstream competition and then for the level of the technology transfer and the level of the fixed fees payed to the upstream firm in period 2. According to the decisions in the previous period of the game, there are four alternative cases provided in the table below.

	no break away zero outside option	no break away rent	break away another retailer hired	break away no other retailer hired
	case 1A	case 1B	case 2A*	case 2B**
h_2	$\frac{a-c}{\tau}$	$\frac{a-c}{\tau}$	$\frac{a-c+h_1}{\tau}$	0
p_2	c	c	$c-h_1$	c
F_2	$(a-c)(\frac{a-c}{\tau}+h_1)$	$\frac{(a-c)^2}{\tau}$	$\left(\frac{a-c+h_1}{\tau}-h_1\right)(a-c+h_1)$	0
Π_2^D	0	$h_1(a-c)$	0	$h_1(a-c)$
Π_2^U	$\frac{(a-c)(a-c+2\tau h_1)}{2\tau}$	$\frac{(a-c)^2}{2\tau}$	$\frac{(a-c+h_1)(a-c-h_1(2\tau-1))}{2\tau}$	0
*This column refers to $h_2^{'}, p_2^{'}, F_2^{'}, \Pi_2^{D'}$ and need $\tau > \frac{1}{2}$ and $h_1 \leq \frac{a-c}{2\tau-1}$				
**For $\tau \leq \frac{1}{2}$ any h_1 drives to case 2B. For $\tau > \frac{1}{2}$ need $h_1 > \frac{a-c}{2\tau-1}$				

Table A2.1: Cases 1A, 1B, 2A, 2B

What is the equilibrium outcome in period 2? Is it more profitable for firm U to make firm D not to break away, by giving her the outside option? After comparing the profits in case 1A to the profits incase 2A, we find that case 1A is more profitable. After comparing case 1B to case 2B, we obtain that case 1B is more profitable, since firm U operates in the market and obtains positive profits. Therefore, the upstream firm always prefers to stay with the initial downstream firm, the one that has been transferred technology in period 1. The equilibrium from period 2 is summarized in Table A2.2.

$\tau \in [0, \frac{1}{2}]$	$\tau \in (\frac{1}{2}, \infty)$	
every h_1	$h_1 \leq \frac{a-c}{2\tau-1}$	$h_1 > \frac{a-c}{2\tau-1}$
case 1B	case 1A	case 1B
no break away	no break away	no break away
rent to D	zero rent to D	rent to D
$h_2 = \frac{a-c}{\tau}$	$h_2 = \frac{a-c}{\tau}$	$h_2 = \frac{a-c}{\tau}$

Table A2.2: Equilibrium in period 2

Period 1

After solving for the equilibrium prices and the level of the technology transfer, we obtain two alternative cases for the U, either it can set a low h_1 in the first period without paying any rent to the D or it can set a high h_1 and pay a rent to firm D (see the tables below).

	h_1	PV
$\tau \in [0, \frac{1}{2}]$	no h_1 with no rent	0
$\tau \in \left(\frac{1}{2}, \frac{2}{3}\right)$	$\frac{(1+\delta)(a-c)}{\tau}$	$\frac{(\delta(\delta+3)+1)(a-c)^2}{2\tau}$
$\tau \in [\frac{2}{3}, 1]$	$\frac{(1+\delta)(a-c)}{\tau}$ if $\delta \leq \frac{1-\tau}{2\tau-1}$ $\frac{a-c}{2\tau-1}$ if $\delta > \frac{1-\tau}{2\tau-1}$	$\frac{(\delta(\delta+3)+1)(a-c)^2}{2\tau}$ $\frac{(\delta(4\tau-1)(2\tau-1)+\tau(3\tau-2))(a-c)^2}{2\tau(2\tau-1)^2}$
$\tau \in (1, \infty)$	$\frac{a-c}{2\tau-1}$	$\frac{(\delta(4\tau-1)(2\tau-1)+\tau(3\tau-2))(a-c)^2}{2\tau(2\tau-1)^2}$

Table A2.3: No rent

	h_1	PV
$\tau \in [0, \frac{1}{2}]$	$\frac{a-c}{\tau}$	$\frac{(a-c)^2(1+\delta)}{2\tau}$
$\tau \in \left(\frac{1}{2}, \frac{1}{7}\sqrt{2}+\frac{3}{7}*\right)$	there is no h_1 with PV>0	0
$\tau \in [\frac{1}{7}\sqrt{2}+\frac{3}{7}, \frac{2}{3})$	no h_1 with PV>0 if $\delta \leq \frac{\tau(2-3\tau)}{(2\tau-1)^2}$ $\frac{a-c}{2\tau-1}$ if $\delta > \frac{\tau(2-3\tau)}{(2\tau-1)^2}$	0 $\frac{(a-c)^2\left(\delta(2\tau-1)^2+\tau(3\tau-2)\right)}{2\tau(2\tau-1)^2}$
$\tau \in [\frac{2}{3}, 1]$	$\frac{a-c}{2\tau-1}$	$\frac{(a-c)^2\left(\delta(2\tau-1)^2+\tau(3\tau-2)\right)}{2\tau(2\tau-1)^2}$
$\tau \in (1, \infty)$	$\frac{a-c}{\tau}$	$\frac{(a-c)^2(1+\delta)}{2\tau}$

*For these τ we take $\delta > \frac{\tau(2-3\tau)}{(2\tau-1)^2} > 1$. Also $\frac{1}{7}\sqrt{2}+\frac{3}{7} \simeq 0.6306$

Table A2.4: Rent

Finally, the U decides whether to pay the rent or not to the downstream firm D by comparing its

PVs in the two cases. By this comparison, we have[16]

	h_1	Rent vs No rent
$\tau \in [0, \frac{1}{2}]$	$\frac{a-c}{\tau}$	rent
$\tau \in \left(\frac{1}{2}, \frac{2}{3}\right)$	$\frac{(1+\delta)(a-c)}{\tau}$	no rent
$\tau \in [\frac{2}{3}, 1]$	$\frac{(1+\delta)(a-c)}{\tau}$ if $\delta \leq \frac{1-\tau}{2\tau-1}$	no rent
	$\frac{a-c}{2\tau-1}$ if $\delta > \frac{1-\tau}{2\tau-1}$	no rent
$\tau \in (1, \infty)$	$\frac{a-c}{\tau}$ if $\delta \leq \frac{(\tau-1)^2}{2\tau(2\tau-1)}$	rent
	$\frac{a-c}{2\tau-1}$ if $\delta > \frac{(\tau-1)^2}{2\tau(2\tau-1)}$	no rent

Table A2.5: Equilibrium

We find that rent is given to D when the cost parameter τ is too low (lower than 0.5) and when the cost parameter is high, but the discount factor δ is low. When τ is low firm U prefers to transfer high technology h_1 in period 1 to lower the marginal cost a lot in that period. When the discount factor is low enough, future does not matter a lot, thus, firm U chooses a high h_1 and gives rent to D in order to enjoy a lower marginal cost in the first period.

[16] Some results are proved numerically.