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ABSTRACT

Licensing Complementary Patents and Vertical Integration*

In this paper we investigate the pricing incentives of IP holders and compare the equilibrium royalty rates charged by vertically integrated IP holders with those of non- integrated IP holders. We show that under many circumstances non-integrated companies are likely to charge lower royalties than their vertically integrated counterparts. The results of this paper are of special relevance for the analysis of competition in CDMA and WCDMA technology licensing, where some IP holders are not vertically integrated into handset and infrastructure manufacturing, while others are.

JEL Classification: D43, L15 and L41
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NON-TECHNICAL SUMMARY

In this paper we investigate whether in technology markets where the holders of essential patents license their technologies non-cooperatively, the equilibrium royalty rates charged by vertically integrated IP holders would be lower than those of non-vertically integrated IP holders.

We first analyze a model where all firms act non-cooperatively and set linear and non-discriminatory royalties. We find that a vertically integrated firm may charge a higher royalty rate than a non-integrated firm and a vertically integrated market may be less efficient than a non-integrated one. Whereas vertical integration eliminates the so-called vertical double marginalization problem, which should lead to lower royalty rates, there is an additional effect under vertical integration that tends to increase royalties. If a vertically integrated firm raises its royalty, it does not affect its own cost but it raises the costs of its competitors on the downstream market. By raising the costs of its downstream rivals the vertically integrated firm increases its downstream market share and its profits.

We then investigate an extension of the basic model where firms can use non-linear royalty contracts. In this case there are multiple equilibria. When firms are non-integrated, upstream firms set non-linear royalty schemes so as to eliminate any vertical distortion: This is not the case for vertically integrated firms, since they still have an incentive to raise their rivals' costs.

Finally, we also consider the possibility of cooperation among competitors. If firms can jointly set royalties through cross-licensing agreements, a club of vertically integrated companies will internalize the effects of horizontal and vertical double marginalization and therefore reduce its royalties as compared to a situation where royalties are set non-cooperatively. However, if vertically integrated firms can charge discriminatory royalties, they have a strong incentive to charge prohibitively high royalties from non-integrated downstream producers in order to eliminate downstream competition. Non-integrated upstream firms, on the other hand, benefit from more downstream competition.

Furthermore, we find that if vertically integrated firms and non-integrated upstream firms agree on a profit-maximizing cross-licensing agreement that shares profits equally, the royalties charged by the non-integrated upstream firm have to be higher than the ones charged by the integrated company, because the upstream firm is not active on the downstream market and has to make its profits upstream.

These results show that non-integrated companies do care about the impact their royalties have on the development of the downstream market and, what is more, that in many cases they may charge lower royalties than their

vertically integrated counterparts. This is not trivial since those royalties represent their only source of income, which is obviously not the case for their vertically integrated competitors.

This is of special relevance for the understanding of competition in CDMA and WCDMA technology licensing, where some IP holders, like Qualcomm, are not vertically integrated into handset and infrastructure manufacturing, while others, like Nokia and Ericsson, are vertically integrated. The results of this paper show that one cannot presume that the latter will have an incentive to set lower royalty rates to third parties than the former, and that in many circumstances the rates charged by the vertically integrated companies will be significantly larger since in this way they can relax downstream competition.

I. INTRODUCTION

Technological standards often require the use of multiple patents that are owned by different patent holders. When the standard is proposed by a standard setting organisation, all holders of patents essential to the proposal are asked whether they are willing to license their essential patents under the IPR conditions established for the standard. Typically, these conditions require that royalty rates be set under fair, reasonable and non-discriminatory (FRAND) terms. Firms contributing their essential patents to the standard may be asymmetric, e.g., because some of them produce downstream products and require licenses from the other firms while others do not produce downstream products and only sell their IP rights, in which case there may be a conflict of interest about what royalties should be charged.

A recent case illustrating this conflict is a complaint by Broadcom, Ericsson, NEC, Nokia, Panasonic and Texas Instruments (hereafter "the complainants") to the European Commission arguing that Qualcomm has behaved abusively within the upstream "technology market" for third generation (3G) phone systems. They have alleged that Qualcomm has abused its dominant position by charging royalties for its WCDMA[1] licenses which are "excessive and disproportionate".[2]

Allegations of abuse raise the issue of whether Qualcomm is dominant. Dominance cannot be assumed just because Qualcomm has patents that are essential for implementing the WCDMA standard. As John Temple Lang noted in a recent paper, "a patent does not necessarily confer an economic monopoly".[3]

However in the same paper he goes on to claim that lack of vertical integration might well imply dominance because unintegrated suppliers are not constrained by what some have called "mutual moderation". Specifically he claims that "the holder of essential patents is likely to be dominant if…the holder has no

[1] Wideband Code-Division Multiple-Access (WCDMA) is one of several different technologies that allow handsets to communicate with base stations within 3G cellular systems (see Section 2).
[2] See Wall Street Journal 29/10/2005, Financial Times 29/10/2005.
[3] See Temple Lang (2006, p. 32).

downstream operations of its own in the licensees' market, which would act as a constraint on its freedom to charge the maximum rate of royalty which the downstream market would bear."[4]

This is an important claim in the context of the complaints against Qualcomm because most of the complainants are both holders of IP in WCDMA, and licensees that use WCDMA technology in mobile handsets. Qualcomm, on the other hand, holds WCDMA IP but is not a handset maker.[5]

If the theory of "mutual moderation" was correct, we should have that in technology markets where the holders of essential patents license their technologies non-cooperatively, the equilibrium royalty rates charged by vertically integrated IP holders should be lower than those of non-vertically integrated IP holders. In addition, we should also find that when there are both vertically integrated and non-integrated IP holders co-existing in the market, the equilibrium royalty rates charged by the former should be unambiguously lower than the royalty rates of the latter.

In this paper we investigate these propositions. We analyze a market where firms (IP holders) are either vertically integrated or non-integrated. In Section 3 we assume that all firms act non-cooperatively and set linear and non-discriminatory royalties. When a non-integrated upstream firm sets its royalty rate, it takes into account that a higher royalty increases marginal costs of the downstream firms and thus reduces the quantity sold on the downstream market. However, it does not take into account that an increase of its royalty rate reduces the licenses sold by the other upstream firms and the profits of the downstream firms. Thus, there is horizontal double marginalization, because essential patents are perfect complements, and vertical double marginalization, because upstream and downstream firms both exercise their market power.

Vertical integration is a standard remedy to solve the vertical double marginalization problem. Within a vertically integrated firm the royalty paid by the downstream division to the upstream division does not affect profits and is not

[4] See Temple Lang (2006, p. 33).
[5] Qualcomm does make WCDMA chips.

treated as a cost. Therefore, the double mark-up problem within a vertically integrated firm (but not across firms) disappears. However, there is an additional effect under vertical integration that tends to increase royalties. If a vertically integrated firm raises its royalty rates, it does not affect its own cost but it raises the costs of its competitors on the downstream market. By raising the costs of its downstream rivals the vertically integrated firm increases its downstream market share and its profits. Therefore, a vertically integrated firm may charge a higher royalty rate than a non-integrated firm and a vertically integrated market may be less efficient than a non-integrated one.

In Section 4, we allow for cooperation among the competitors. If firms can jointly set royalties through cross-licensing agreements a club of vertically integrated companies will internalize the effects of horizontal and vertical double marginalization and therefore reduce the club's royalties as compared to a situation where royalties are set non-cooperatively. However, the vertically integrated companies still have an incentive to raise the costs of their non-integrated downstream rivals. In fact, if vertically integrated firms can charge discriminatory royalties, they have a strong incentive to charge prohibitively high royalties from non-integrated downstream producers in order to eliminate downstream competition. Non-integrated upstream firms, on the other hand, benefit from more downstream competition. Furthermore, we find that if vertically integrated firms and non-integrated upstream firms agree on a profit-maximizing cross-licensing agreement that shares profits equally, the royalties charged by the non-integrated upstream firm have to be higher than the ones charged by the integrated company, because the upstream firm is not active on the downstream market and has to make its profits upstream.

The same result holds if firms collude in an infinitely repeated game. If firms are required to charge symmetric royalties, there is a conflict of interest between integrated and non-integrated firms. Integrated firms prefer low royalties in order to shift profits to the downstream market while non-integrated upstream firms prefer higher royalties in order to shift profits upstream.

We also look at the case where firms can use non-linear royalty contracts. In this case there are always multiple equilibria. If firms are non-integrated, upstream firms will set non-linear royalty schemes so as to eliminate any vertical distortion, which will not be the case for vertically integrated firms, since they have an incentive to raise their rivals' costs.

Finally, we show that if upstream firms had different costs to develop their technologies, this could be reflected in different royalties, and this asymmetry in royalties would be efficient.

These results have implications for the incentives of the parties in the Qualcomm case. Non-integrated companies such as Qualcomm care about the impact their royalties have on the development of the downstream market, despite the fact that they are not active in that downstream market. Furthermore, in many cases, the non-integrated firms have incentives to charge lower royalties than their vertically integrated counterparts would optimally charge. This is not trivial since those royalties represent their only source of income, which is obviously not the case for their vertically integrated competitors.

As a result, the "mutual moderation" theory developed by John Temple Lang cannot be relied on. Qualcomm has no greater incentive to charge excessive prices than the complainants, and as the paper shows, may in fact have incentives to charge significantly less.

The incentives to raise one's rivals' cost has first been analysed by Salop and Scheffman (1983, 1987). However, they restrict attention to a dominant firm that can affect marginal and average costs of a competitive fringe. They show that the dominant firm will raise its rivals' cost in order to either foreclose the market or to induce competitors to raise their prices and to relax competition. Our model is closer to Ordover, Saloner and Salop (1990) and Kim (2004). Ordover et al. consider a two-stage duopoly model with price competition and differentiated products. However, they consider the more conventional case where the goods produced upstream are perfect substitutes while we look at the opposite case of perfect complements. In

their model a vertically integrated firm must be able to commit ex ante to a price for the input good, even though there is an incentive to reduce this price ex post. No such commitment is necessary in our model. Furthermore, in Ordover et al. (1990) there is a foreclosure effect only if downstream firms compete in prices (so that strategies are strategic complements) while our results are established for quantity competition. Kim (2004) analyses a model similar to ours, but he restricts attention to the case of a linear demand curve. Shapiro (2001) discusses the case of patents that are perfect complements and argues that patent pools and cross licensing agreements can be a solution to the complements problem. However, he does not consider the difference between vertically integrated and non-integrated firms.

The remainder of this paper is organised as follows: Section 2 presents some basic information which will help the reader understand the industry background of the Qualcomm case and, in particular, the interactions among the holders of essential patents in the 3G mobile telephony industry. Section 3 provides the basic model of competitive interactions by vertically integrated and non-integrated firms on the upstream and downstream market. Section 4 extends the basic model in several ways. First, it investigates equilibrium cross-licensing agreements; second, it considers the implications of collusion through repeated interaction; third, it discusses the case of non-linear royalties; and finally it extends the basic model to consider the incentives to invest in R&D. Section 5 concludes.

II. BACKGROUND

This section provides a description of the basic concepts needed to understand the 3G telephony industry.

All wireless telephone systems contain certain fundamental elements, among them the air interface for communication between a handset and a base station and the core network for handling calls after they reach a base station. WCDMA has been selected as the air interface for the successor to the GSM mobile system – Universal Mobile Telecom System (UMTS). The companies working on UMTS have submitted

essential patents for the various complementary elements of the standard, including WCDMA.

The European Telecommunications Standards Institute (ETSI), the standard setting organization coordinating UMTS efforts, has defined essential patents as those patents for which "… it is not possible on technical (but not commercial) grounds, taking into account normal technical practice and the state of the art generally available at the time of standardization, to make, sell, lease, otherwise dispose of, repair, use or operate equipment or methods which comply with a standard without infringing that IPR."[6]

Owners of patents essential to the UMTS standard, license their essential patents for royalties to manufacturers of infrastructure equipment and handsets. Some of the owners of these patents are also present in the downstream infrastructure and handset manufacturing industries. For example, Qualcomm used to be both a patent holder and a manufacturer of handsets and infrastructure equipment, but is no longer a downstream manufacturer. Nokia claims to hold essential patents and manufactures both infrastructure equipment and handsets. Texas Instruments, on the other hand, makes chips for handsets but does not claim any appreciable number of patents and is not a handset manufacturer. Panasonic likewise claims few relevant patents but manufactures handsets and not chips.

Patent licenses are bilaterally negotiated between the owners of essential patents and the companies that want to manufacture products that implement or use the patents. These negotiations typically result in cross-licensing agreements. The non-integrated handset and infrastructure equipment manufacturers negotiate licences between the patent holders on an individual basis. For instance, Qualcomm has licensed numerous companies under its patent portfolio for the manufacture and sale of handsets and infrastructure equipment.

For modelling purposes we will therefore consider a two layered industry: the *upstream* layer where Qualcomm, Nokia and others set royalty rates acting non-

[6] See European telecommunications Standards Institute, "ETSI Intellectual Property Rights Policy". Available at http://www.etsi.org/legal/home.htm.

cooperatively or cooperatively, depending on the model, and the *downstream* layer where Nokia, Texas Instruments, Panasonic and others compete as equipment/handset manufacturers.

III. THE BASE MODEL

Consider a market with an upstream and a downstream segment. On the upstream market there are n firms, indexed by $u = \{1,\ldots,n\}$, each owning an essential patent that is required for downstream production. Patents are perfect complements, i.e., each downstream producer needs a license for each of the patents to carry out production. There is an initial stage 0 at which the upstream firms had to invest into research and development in order to produce the patents. These costs are sunk when the patents are licensed to downstream producers. Assume there are no further production costs upstream. At stage 1 each upstream firm has to decide on the royalty r_u it charges for the use of its patent. Here we assume that upstream firms cannot discriminate between different downstream producers and that royalties are linear in downstream production. In Section 4 we also consider two part tariffs and discrimination.

On the downstream market there are m producers, indexed by $d = \{1,\ldots,m\}$, selling a homogenous good to consumers. Each firm has constant marginal cost

$$c_d = k + r_d$$

where k is the physical cost of production and $r_d = \sum r_u$ is the sum of the royalties that firm d has to pay to upstream firms for each unit of production. Note that if a firm is vertically integrated, it does not have to pay royalties to itself.

For simplicity we assume that there is a homogenous good sold on the downstream market and that downstream firms compete in quantities, q_d. They face an inverse demand function $P(Q)$, with $Q = \sum_{d=1}^{m} q_d$. This Cournot model captures

the idea of an oligopolistic downstream market on which firms have some market power in simplest form. The model could be generalized to a model with differentiated products (as in Dixit, 1979) with either price or quantity competition or to a model in which downstream firms first have to invest in capacity before they compete in prices (as in Kreps and Scheinkman, 1983).

It is assumed throughout that there exists a $\overline{Q}$ such that $P(Q) > 0$ for all $Q < \overline{Q}$ and that $P(Q) = 0$ for all $Q \geq \overline{Q}$. $P(Q)$ is twice continuously differentiable with $P'(Q) < 0$ for all $Q < \overline{Q}$. Furthermore, $P'(Q) + q \cdot P''(Q) < 0$ for all $0 < q < Q < \overline{Q}$. These assumptions ensure that quantities are strategic substitutes and that a Cournot equilibrium exists and is unique.[7] For illustrative purposes we will sometimes consider the example of a linear inverse demand function,

$$P(Q) = a - b \cdot Q$$

with $a > k$ and $b > 0$. In this case it is possible to derive a closed form solution of the model. However, our qualitative results do not depend on this example.

The time structure of the model is as follows. R&D investments have been sunk by the upstream firms at stage 0. At stage 1 each upstream firm chooses a linear and non-discriminatory royalty r_u for its patent. At stage 2 each downstream firm chooses which quantity q_d to produce. The total quantity $Q = \sum_{d=1}^{m} q_d$ determines the market price $P(Q)$ and profits

$$\begin{aligned} \Pi_u &= r_u \cdot Q, \quad u \in \{1,...,n\} \\ \Pi_d &= [P(Q) - c_d] \cdot q_d, \quad d \in \{1,...,m\} \end{aligned}$$

of upstream and downstream firms, respectively.

In this section we compare the case of non-integration, where upstream and downstream firms are owned separately, to the case where all firms are vertically

[7] See e.g. Novshek (1985) and Shapiro (1989, p. 335). Slightly more general conditions that guarantee existence and uniqueness are offered by Amir (1996) and Gaudet and Salant (1991).

integrated. Furthermore, we also briefly discuss the case where some vertically integrated and some non-integrated firms coexist.

Case 1: Non-Integration

We solve the game by backward induction. At stage 2 downstream firms compete in quantities. Without vertical integration all firms have identical marginal cost $c = k + r$, $r = \sum_{u=1}^{n} r_u$. Each downstream firm maximizes $\Pi_d = \left[P\left(\sum_{j=1}^{m} q_j\right) - k - \sum_{u=1}^{n} r_u \right] \cdot q_d$. The FOC for a profit maximum requires

$$\frac{\partial \Pi_d}{\partial q_d} = \left[P(Q) - k - r \right] + \frac{\partial P}{\partial Q} \cdot q_d = 0 \tag{1}$$

There exists a unique Nash equilibrium in which each downstream firm produces $q^{NI}(m,r)$ which is decreasing in m and in r.[8] Total output is given by $Q^{NI}(m,r) = m \cdot q^{NI}(m,r)$ and the market price is $P^{NI}(Q^{NI}(m,r))$. If the number of downstream firms increases, total output increases and the market price decreases. An increase of the total royalty rate r reduces total output and therefore increases the market price.

Let us compute the equilibrium for a linear inverse demand function for future reference. Note that if $a \le c$ all firms would produce a quantity of 0 and make zero profits, so we restrict attention to $a > c$. In equilibrium each firm produces

$$q_d^{NI} = \frac{a - k - r}{(m+1) \cdot b} \tag{2}$$

The total quantity produced by the m firms is $Q^{NI} = \frac{m}{m+1} \cdot \frac{a-k-r}{b}$ and the market price is

$$P^{NI}(m,r) = \frac{a + m \cdot (k+r)}{(m+1)} \tag{3}$$

[8] See Shapiro (1989, p. 341) and Seade (1985).

Note that the market price is decreasing in the number of competitors and approaches marginal cost $c = k + r$ as m goes to infinity.

At stage 1, each upstream firm $u \in \{1, \ldots, n\}$ chooses its royalty rates r_u non-cooperatively in order to maximize $\Pi_u = r_u \cdot Q^{NI}$. The first order condition of this maximization problem is

$$\frac{\partial \Pi_u}{\partial r_u} = \underbrace{Q}_{>0} + \underbrace{\frac{\partial Q}{\partial r_u} \cdot r_u}_{<0} = 0 \tag{4}$$

Thus, a non-integrated upstream firm takes into account that an increase of its royalty rate r_u reduces the total quantity produced on the downstream market $\left(\partial Q / \partial r_u < 0\right)$. However, it only considers the effect on its own profit and does not take into account the external effects of raising r_u on other parties. There are external effects on the other upstream firms, on downstream firms, and on consumers:

- *Complements Effect:* Because patents are perfect complements, an increase in r_u reduces not only the demand for firm u's patent, but also the demand for the patents owned by the other upstream firms and thus reduces their profits. This is a form of horizontal double marginalization.
- *Double Mark-up Effect:* Because each patent is an essential input for downstream production, an increase in r_u increases marginal costs of all downstream producers and thus reduces their profits.[9] This is a form of vertical double marginalization.

[9] An increase of r_u decreases downstream profits if and only if $-QP''(Q)/P'(Q) < 2$, i.e. if the elasticity of the slope of the inverse demand function is not too large. If this condition is violated, an increase of the marginal cost of all firms increases the market price by so much that profits increase. See Shapiro (1989, p. 341) and Seade (1985). However, this requires that demand is inelastic. This cannot be the case in the equilibrium of our two-stage game where royalties have been set optimally.

- *Consumer Surplus Effect*: Because each upstream firm is the sole source for its essential patent, an increase in r_u increases the price consumers have to pay and thus reduces consumer surplus.

Because all these external effects are negative, upstream firms choose royalties that are too high from a social planner's point of view.

To illustrate these effects consider again the model with a linear demand function. In the symmetric equilibrium each upstream firm chooses the same royalty

$$r_u^{NI} = \frac{a-k}{n+1} \tag{5}$$

$u = 1,\ldots,n$, and the sum of all royalties is given by $r^{NI} = \sum_{u=1}^{n} r_u = \frac{n}{n+1} \cdot (a-k)$.[10] This implies that total downstream production is $Q^{NI}(m,n) = \frac{m \cdot (a-k)}{(m+1) \cdot (n+1) \cdot b}$ and the resulting market price is

$$P^{NI}(m,n) = \frac{(mn+n+1) \cdot a + m \cdot k}{(m+1) \cdot (n+1)} \tag{6}$$

Note that the market price is decreasing in m, the number of downstream firms, but *strictly increasing* in n, the number of upstream firms! If n goes to infinity, the market price goes to a and the total quantity sold goes to 0. This is due to the fact that the patents of the upstream firms are perfect complements that are all required for downstream production. Thus, the more upstream firms there are, the larger is the distortion due to their monopoly power and the complements effect.

Case 2: Vertical Integration

[10] There are also "no trade" equilibria in which all upstream firms choose royalties that are so high that there is no trade on the downstream market. For example, it is a Nash equilibrium that all upstream firms choose $r_u = a-k$ and all downstream firms choose $q_d = 0$. However these equilibria involve weakly dominated strategies and will be ignored in the following.

The traditional instrument to deal with double marginalization is vertical integration. However, as we will show here, vertical integration gives rise to a new effect that increases royalties and may further reduce social welfare.

Suppose that each upstream firm is vertically integrated with a downstream firm and vice versa, i.e. $n = m$. Each vertically integrated firm $i \in \{1,\ldots,n\}$ maximizes the sum of upstream and downstream profits. Note that when firm i decides on its downstream production level, it will ignore the royalty rate r_i charged by its own upstream division. Therefore, the marginal cost

$$c_i\left(\overrightarrow{r_{-i}}\right) = k + \sum_{j \neq i} r_j \tag{7}$$

of firm i depends on the vector of royalties, $\overrightarrow{r_{-i}} = (r_1,\ldots,r_{i-1},r_{i+1},\ldots,r_n)$, charged by all other firms.

At stage 2 each firm maximizes $\Pi_i = r_i \cdot \sum_{j \neq i} q_j + \left[P\left(\sum_{j=1}^{m} q_j\right) - k - \sum_{j \neq i} r_j \right] \cdot q_i$. The FOC for a profit maximum requires

$$\frac{\partial \Pi_i}{\partial q_i} = \left[P(Q) - k - \sum_{j \neq i} r_j \right] + \frac{\partial P}{\partial Q} \cdot q_i = 0 \tag{8}$$

There exists a unique Nash equilibrium in the Cournot game at stage 2 in which firms choose quantities $q_i^{VI}(n,\vec{r})$. Summing up the FOCs (8) over all $i = \{1,...,n\}$, we get

$$n \cdot P(Q^{VI}) - n \cdot k - (n-1) \cdot r + \frac{\partial P}{\partial Q} \cdot Q^{VI} = 0 \tag{9}$$

Note that total quantity Q^{VI} depends only on the sum of all marginal costs which is $nk + (n-1)r$, with $r = \sum_{i=1}^{n} r_i$. Similarly, if we sum up FOCs (1) over all $d = \{1,...,n\}$ we get

$$n \cdot P\left(Q^{NI}\right) + n \cdot k + n \cdot r + \frac{\partial P}{\partial Q} \cdot Q^{NI} = 0 \tag{10}$$

Comparing (9) and (10) we see that if the same royalty rates are charged under vertical integration and under non-integration then the total quantity produced under vertical integration is larger, $Q^{VI}(n,\vec{r}) > Q^{NI}(n,\vec{r})$, and the market price is lower. The reason is that a downstream producer will not treat the royalty charged by the upstream division of his firm as a cost because it is a mere transfer payment. Thus, vertical integration solves the double mark-up problem within each firm. Note, however, that the double mark-up problem across firms remains, because firm i does not take into account the effect of r_i on firm j's downstream profit.

What royalties will be chosen under vertical integration? At stage 1, firm i chooses royalty r_i in order to maximize the sum of profits in its upstream and downstream division:

$$\Pi_i = \underbrace{r_i\left[Q^{VI}\left(\vec{r}\right) - q_i\left(\vec{r}\right)\right]}_{upstream\_profit} + \underbrace{q_i\left(\vec{r}\right)\cdot\left[P\left(Q^{VI}\left(\vec{r}\right)\right) - c_i\left(\vec{r_{-i}}\right)\right]}_{downstream\_profit} \tag{11}$$

Differentiating with respect to r_i the FOC for the optimal r_i requires:

$$\frac{\partial \Pi_i}{\partial r_i} = \underbrace{\left[Q - q_i\right]}_{>0} + \underbrace{\left[\frac{\partial Q}{\partial r_i} - \frac{\partial q_i}{\partial r_i}\right]\cdot r_i}_{<0} + \underbrace{\frac{\partial q_i}{\partial r_i}\cdot\left[P - c_i\right]}_{>0} + \underbrace{q_i \cdot \frac{\partial P}{\partial Q}\frac{\partial Q}{\partial r_i}}_{>0} = 0 \tag{12}$$

The first two terms of (12) correspond to (4), the FOC under non-integration: An increase in r_i raises revenues per unit of output, but it reduces the quantity of output. There is one difference to (4) though: Because the revenue from its own downstream division is not a profit, the vertically integrated firm does not consider the entire downstream market, but only the market that is served by the other firms.

The last two terms of (12) reflect the effect of an increase of r_i on downstream profits and have no analogue in (4). By increasing its royalty rate r_i firm i does not affect its own marginal cost but it increases the marginal costs of its downstream competitors $j \neq i$. Thus, in the downstream continuation equilibrium the quantities chosen by all other firms are reduced while the quantity of firm i goes up.

Therefore, the third term in (12) which captures the effect that firm i receives the mark up, $P - c_i$, on a larger quantity is positive. The forth term is also positive. As we have shown above, for general demand functions total Cournot quantity Q depends on the sum of all marginal costs only. If r_i increases, firm i's marginal cost is unaffected while the marginal costs of all other firms increase. Thus, the sum of all marginal costs goes up, total quantity goes down $\partial Q / \partial r_i < 0$ and the market price $P(Q)$ goes up which benefits firm i. Therefore, the royalties chosen under vertical integration may be larger than under non-integration!

This "raising-one's -rivals'-cost effect" implies that each vertically integrated firm has an incentive to raise its royalty rate in order to improve its own market position to the detriment of its rivals. However, this is a prisoner's dilemma. In equilibrium all vertically integrated firms choose the same royalty, nobody has a competitive advantage, and everybody would be better off if all firms could jointly reduce their royalties.

To illustrate the raising-one's-rivals'-cost effect consider again the example of a linear demand curve. There is a unique Nash equilibrium on the downstream market where firm i chooses quantity

$$q_i = \frac{a - n \cdot c_i + \sum_{j \neq i} c_j}{(n+1) \cdot b} = \frac{a - k + (n-1) r_i - 2 \sum_{j \neq i} r_j}{(n+1) \cdot b} \tag{13}$$

and total downstream production is given by $Q^{VI} = \frac{n \cdot (a-k) - (n-1) \cdot r}{(n+1) \cdot b}$, with $r = \sum_{i=1}^{n} r_i$. Thus, the price on the downstream market is given by

$$P^{VI}(n, \vec{r}) = \frac{a + n \cdot k + (n-1) \cdot r}{n+1} \tag{14}$$

At stage 1 there is a unique symmetric equilibrium in which each firm charges royalty

$$r_i^{VI} = \frac{(a-k)\cdot(n+3)}{n^2+4n-1} \tag{15}$$

In order to compare the royalties by vertically integrated firms to the royalties charged under non-integration suppose that there is an equal number of upstream and downstream firms $(m=n)$ under non-integration and that this number is equal to the number of vertically integrated firms (n). Comparing (5) to (15) it is easy to show that for all n

$$r_i^{VI} > r_u^{NI} \tag{16}$$

Thus, royalties charged by vertically integrated firms are always higher than royalties charged by non-integrated firms.

On the other hand, vertical integration partially solves the double mark-up problem. Within a vertically integrated firm the royalty charged is effectively zero, so there is no double marginalization within a firm. However, the double mark-up problem remains between firms and is aggravated by the raising-one's-rivals'-cost effect. Which effect dominates depends on the demand function.

In the case of a linear demand curve, plugging in the result for r_i^{VI} yields a total output $Q^{VI}(n) = \frac{2n(a-k)}{b(n^2+4n-1)}$ and the market price

$$P^{VI}(n) = \frac{(n^2+2n-1)\cdot a + 2nk}{n^2+4n-1} \tag{17}$$

In a non-integrated industry we have seen that the market price decreases with the number of competitors in the downstream market but increases with the number of firms in the upstream market. With vertical integration the number of upstream and downstream firms is required to be equal. It can be shown that if the number of vertically integrated firms increases, the price goes up. Thus, the complements effect, the double mark-up effect across firms and the raising-one's-rivals'-cost effect dominate the positive effect of more downstream competition. It can also be shown that with an equal number of (upstream) firms the final output

price under vertical integration is smaller than under non-integration, but this result depends on the shape of the demand curve.

Case 3: Coexistence of Vertically Integrated and Non-Integrated Firms

We briefly consider the case with n vertically integrated firms, indexed by $i \in \{1,...,n\}$, one firm u that is active only on the upstream market and one firm d that is active only on the downstream market. The extension to several non-integrated firms on the upstream and/or downstream market is straightforward.

For any vector of royalties $\vec{r} = (r_u, r_1, ..., r_n)$ vertically integrated firms have marginal cost $c_i = k + r_u + \sum_{j \neq i} r_j$ while the downstream firm has marginal cost of $c_d = k + r_u + \sum_{j=1}^{n} r_j$. Note that $c_d \geq c_i$ for all $i \in \{1,...,n\}$. Therefore, in the unique Cournot-Nash equilibrium of the downstream market $q_d^{CoX} \leq q_i^{CoX}$. In fact, in equilibrium the vertically integrated firms may choose royalties that are so high that firm d cannot compete downstream and chooses $q_d^{CoX} = 0$. This is the case in the example with a linear demand curve (see Kim 2004).

At stage 1 firms that are active on the upstream market have to decide on their royalties. The profit of the non-integrated upstream firm u is given by $\Pi_u = r_u \cdot Q^{CoX}$, where $Q^{CoX} = q_d^{CoX} + \sum_{i=1}^{n} q_i^{CoX}$ The first order condition of this maximization problem is $\frac{\partial \Pi_u}{\partial r_u} = Q + \frac{\partial Q}{\partial r_u} \cdot r_u = 0$ as in (4).

The profit of a vertically integrated firm i is given by $\Pi_i = r_i \left[Q^{CoX}\left(\vec{r}\right) - q_i^{CoX}\left(\vec{r}\right) \right] + q_i\left(\vec{r}\right) \cdot \left[P\left(Q^{CoX}\left(\vec{r}\right)\right) - c_i\left(\overrightarrow{r_{-i}}\right) \right]$. Differentiating with respect to r_i yields:

$$\frac{\partial \Pi_i}{\partial r_i} = \underbrace{\left[Q - q_i\right]}_{>0} + \underbrace{\left[\frac{\partial Q}{\partial r_i} - \frac{\partial q_i}{\partial r_i} \right] \cdot r_i}_{<0} + \underbrace{\frac{\partial q_i}{\partial r_i} \cdot \left[P - c_i\right]}_{>0} + \underbrace{q_i \cdot \frac{\partial P}{\partial Q} \frac{\partial Q}{\partial r_i}}_{>0} = 0 \qquad (18)$$

This is the same expression as (12). Comparing the incentives for raising the royalty rate of the non-integrated upstream firm u to a vertically integrated firm i, it is easy to see that a vertically integrated firm may choose a larger royalty than the non-integrated upstream firm. In fact, this is the case in the example with a linear demand curve.

IV. EXTENDING THE BASE MODEL

So far we assumed that all firms choose their strategies non-cooperatively. Now we consider the possibility that firms coordinate their behaviour, either through an explicit cross licensing agreement on the upstream market (Section A) or through an implicit agreement that is sustained as an equilibrium in an infinitely repeated game (Section B). In both cases we compare a situation in which all firms are vertically integrated to a situation with some vertically integrated and some non-integrated upstream and downstream firms. In both cases it is possible to implement the monopoly outcome if firms cooperate. However, we will show that the asymmetry between vertically integrated and non-integrated firms gives rise to a conflict of interest about the structure of royalties.

In Section C we look at more complicated pricing strategies and allow for non-linear royalties and price discrimination. We show that if the industry is non-integrated, then there exists an equilibrium in which the complements problem and the double mark-up problem disappear. Furthermore, non-integrated upstream firms do not have an incentive to discriminate against any downstream firms. If the industry is vertically integrated however, the (constrained efficient) equilibrium under non-integration breaks down. Each vertically integrated firm has an incentive to raise the royalties for the other firms in order to monopolize the downstream market. Furthermore, vertically integrated firms have an interest to discriminate against non-integrated downstream producers.

Finally, in Section D we extend the model by analyzing the initial stage 0 at which the R&D investment decisions have to be taken that are necessary to develop the technologies behind the patents in the first place.

A. Cross Licensing Agreements

Suppose that there are n vertically integrated firms that can write a cross-licensing agreement that fixes the vector of royalties $\vec{r} = (r_1, ..., r_n)$ at stage 1. At stage 2 they compete on the downstream market and set quantities q_i, $i \in \{1, ..., n\}$ non-cooperatively. We first derive the Cournot equilibrium for a given vector of royalties. Then we show that firms can contractually fix a vector of royalties that implements the monopoly outcome.

The analysis of stage 2 is exactly the same as the one of Case 2 in Section 3. Each firm's marginal cost $c_i = k + \sum_{j \neq i} r_j$ depends on the royalties charged by the other firms but not on its own royalty. There exists a unique Nash equilibrium in which each firm chooses $q_i^{CL}(n, \vec{r})$, total output $Q^{CL}(n, \vec{r})$ is characterized (3.9), and the market price is $P\left(Q^{CL}(\vec{r}, n)\right)$. If the demand function is linear, $q_i^{CL}(n, \vec{r})$ is given by (3.13), total Cournot quantity is $Q^{CL} = \frac{n \cdot (a-k) - (n-1) \cdot r}{(n+1) \cdot b}$ and the market price is

$$P^{CL}(n, \vec{r}) = \frac{a + n \cdot k + (n-1) \cdot r}{n+1} \tag{19}$$

At stage 1, the parties would like to write a cross-licensing agreement that maximizes their total profits. As a reference point let us characterize the monopoly outcome. A monopolist who owns all the patents $i \in \{1, ..., n\}$ and who is the only downstream producer maximizes

$$\Pi^M = Q \cdot \sum_{i=1}^{n} r_i + \left[P(Q) - k - \sum_{i=1}^{n} r_i \right] \cdot Q = \left[P(Q) - k \right] \cdot Q \tag{20}$$

For a monopolist, the sum of all royalties $r = \sum_{i=1}^{n} r_i$ is irrelevant because it is just a transfer payment from her downstream to her upstream division. Therefore, her only problem is to choose the monopoly quantity Q^M that is characterized by the first order condition

$$P(Q^M) + \frac{\partial P(Q^M)}{\partial Q} \cdot Q^M = k \tag{21}$$

In case of a linear demand function the monopoly quantity is $Q^M = \frac{a-k}{2b}$, the monopoly price is $P^M = \frac{a+k}{2}$, and the monopoly profit is $\Pi^M = \frac{(a-k)^2}{4b}$.

We will now show how the parties can implement the monopoly outcome. The implicit function theorem implies that the Cournot quantity that is chosen at stage 2 and that is characterized by (9) is a continuous and strictly decreasing function of r. If $r = 0$, firms have marginal cost of k and choose a total Cournot quantity that is larger than the monopoy quantity. If r is sufficiently large, the total Cournot quantity is smaller than the monopoly quantity. Hence, by the intermediate-value theorem there exists an r^M such that if the sum of the royalties charged by all firms is r^M, then the total Cournot quantity induced by these royalties is $Q^{CL}\left(n, r^M\right) = Q^M$. Note that it does not matter for the implementation of the monopoly outcome how royalties $\left(r_1^{CL}, ..., r_n^{CL}\right)$ are allocated across firms as long as $\sum_{i=1}^{n} r_i^{CL} = r^M$. However, if firms are symmetric it is natural to assume that firms agree on reciprocal royalty rates $r_i^{CL} = r^M / n$.

In the example with a linear demand curve, r^M solves

$$Q^{CL}(n, r^M) = \frac{n \cdot (a-k) - (n-1) \cdot r^M}{(n+1) \cdot b} = \frac{a-k}{2b} = Q^M \tag{22}$$

which is equivalent to

$$r^M = \frac{a-k}{2}. \tag{23}$$

If royalty rates are symmetric, we get $r_i^{CL} = (a-k)/2n$.

Cross-licensing agreements can be used to sustain the monopoly outcome. Note, however, that the monopoly outcome is a welfare improvement as compared to the situation in Section 3 where parties had to set royalty rates independently. In particular, if firms can write cross-licensing agreements, they will use these agreements to solve the complements problem and the double mark-up problem. Furthermore, the raising-one's-rivals-cost effect disappears, because parties can solve the prisoners' dilemma by jointly fixing the royalty rates in their cross licensing agreement. Only the consumer surplus effect remains.

Suppose now that in addition to the n vertically integrated firms there are some non-integrated downstream firms. In this case the double-mark-up effect and the raising-one's-rival's-cost effect raise their ugly heads again, but they are less severe than without cross licensing agreements. When the vertically integrated firms negotiate the cross-licensing agreement, they do not internalize the effect of their royalties on the profits of the non-integrated downstream firms and they have an incentive to jointly raise their royalty rates in order to raise the costs of their non-integrated downstream competitors.

What happens if in addition to the n integrated firms there are some non-integrated upstream firms. There is no problem to induce the monopoly outcome by writing a cross-licensing agreement that induces a total output that is equal to the monopoly output. However, if firms want to share the monopoly profit equally, they have to use asymmetric royalties. Because the non-integrated firms make no profits downstream they have to get higher royalties than the vertically integrated firms.

If firms were constrained to charge equal royalties independent of whether they are active on the downstream market or not, a conflict of interest arises. Vertically integrated firms prefer a royalty rate that is lower than the one that implements the monopoly outcome, because the vertically integrated firms want to

shift some profits from the upstream to the downstream market at the expense of the non-integrated upstream firms. On the other hand, the non-integrated upstream firms prefer a royalty rate that is higher than the royalty rate that implements the monopoly outcome because they want to shift profits from the downstream to the upstream market. How royalties are allocated depends on the bargaining procedure and the relative bargaining power of the players.

To illustrate that very unequal allocations of royalties may arise, consider the following bargaining procedure. Suppose that there is one non-integrated upstream firm and n vertically integrated firms that are completely symmetric. Suppose further that the vertically integrated firms will always find an agreement among themselves that maximizes their joint surplus. At date 0 the integrated firms negotiate with the upstream firm on their respective royalties. Suppose that the n integrated firms can make a joint offer to the upstream firm. If the offer is rejected, the upstream firm opts out and sets its royalty rate r_u unilaterally. The n vertically integrated firms will then choose their royalties so as to maximize their joint surplus.

We solve the game by backward induction. Suppose that the offer was rejected and that the upstream firm charges r_u. All of the vertically integrated firms have to pay r_u, so this increases their marginal production cost to $k + r_u$. Thus, the largest profit they can now jointly obtain is the profit of a monopolist with cost $k + r_u$. With a linear demand curve the monopoly quantity is given by $Q^M(r_u) = \frac{a - k - r_u}{2b}$ and the monopoly price is given by $P^M(r_u) = \frac{a + k + r_u}{2}$. In order to realize the monopoly profit, the vertically integrated firms will agree on royalties

$$r^M(r_u) = \frac{a - k - r_u}{2n} \tag{24}$$

Anticipating this, the upstream firm will choose r_u in order to maximize $\Pi_U = r_u \cdot Q^M(r_u)$. The solution to this maximization problem is

$$r_u = \frac{a-k}{2} \tag{25}$$

to which the n vertically integrated firms will react with $r^M(r_u) = \frac{(a-k)}{4n}$. Thus, the total quantity on the market is $Q^M(r_u) = \frac{a-k}{4b}$ and the upstream firm makes profit

$$\Pi_u = \frac{(a-k)^2}{8b} \tag{26}$$

Hence, when the vertically integrated firms make a take-it-or-leave-it offer to the upstream firm they have to offer a package that gives at least this profit (half the monopoly profit!) to the upstream firm.

Of course, this specific example of a bargaining procedure is somewhat arbitrary. However, it may be realistic if the upstream firm can credibly threaten to opt out and to set its royalty rate non-cooperatively, and if the vertically integrated firms are symmetric and more likely to cooperate with each other than with the upstream firm.

B. Collusion through Repeated Interaction

Consider the model of the Section 3 with n vertically integrated firms that interact repeatedly. In each period t, $t = 1, 2, ...$ there are two stages: At stage1 each firm chooses its royalty rate, r_i^t, to be charged on the upstream market. At stage 2 each firm chooses quantities q_i^t to be supplied on the downstream market. The market price in period t, $P^t(Q^t)$, is a function of total quantity $Q^t = \sum_{i=1}^n q_i^t$. Thus, firm i's profit in period t is given by

$$\Pi_i^t = r_i^t Q^t(\vec{r^t}) + \left[P^t\left(Q^t(\vec{r^t})\right) - c_i^t(\vec{r_{-i}^t}) \right] \cdot q_i^t(\vec{r^t}) \tag{27}$$

The repeated game played by the firms is open-ended in the sense that in each period there is a positive probability that the interaction continues in the next period.

This is modelled as an infinitely repeated game in which firms maximize the sum of their discounted future profits

$$\Pi_i = \sum_{t=1}^{\infty} \delta^{t-1} \cdot \Pi_i^t \tag{28}$$

The common discount factor $\delta \in (0,1)$ reflects the interest rate that has to be used to discount future profits and the length of the time period that depends on how quickly firms can change their royalties and quantities. Furthermore, it reflects the probability that the game is continued in the next period. The smaller the interest rate, the shorter the time period and the higher the probability that the game is continued, the closer is the discount factor to 1.[11]

It is well known that in an infinitely repeated Cournot game the parties can sustain the monopoly outcome as a subgame perfect equilibrium if they are sufficiently patient, i.e., if δ is close enough to one. In our model the following trigger strategies with Nash reversion are a simple example for a subgame perfect equilibrium that implements the monopoly outcome:

In period 1 all firms $i \in \{1,\ldots,n\}$ set royalties $r_i^1 = 0$ and, if each firm did so, quantities $q_i^1 = Q^M / n$. In period t, $t = 2,...,\infty$, all firms continue to choose these royalties and quantities as long as no firm deviated from this strategy in any previous period. If there is any deviation in any period t', all firms $i \in \{1,\ldots,n\}$ set royalties $r_i^t = r_i^{VI}$ and quantities $q_i^t = q_i^{VI}\left(\vec{r^t}\right)$ in all subsequent periods $t \in t'+1,...,\infty$.[12]

For this equilibrium, royalty rates of 0 are not important.[13] Royalty rates can be used to shift profits between the downstream and the upstream market and between firms.

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[11] See Oborne and Rubinstein (1994, pp. 134-136) for a discussion on how to model repeated interaction.

[12] It is straightforward to show that there exists a $\underline{\delta}<1$, such that for all $\delta>\underline{\delta}$ these strategies are a subgame perfect equilibrium.

[13] Note, however, that if royalty rates are contractually fixed for several periods, zero royalty rates have the advantage that they allow for an effective punishment if a player deviates: the lower the royalty rates, the larger are the quantities $q_i^{VI}\left(\vec{r^t}\right)$ produced after a deviation and the lower are the continuation profits for a deviator.

Suppose now that in addition to the n vertically integrated firms there are some additional firms that are active only on the upstream market. These firms do not make any profits downstream. Therefore, there is a conflict of interest. While all the n integrated firms have a joint interest in setting the royalty rates as low as possible in order to shift profits to the downstream market, the upstream firm wants a royalty rate for its own patent that is as high as possible (up to the monopoly price). There are many different equilibria with different allocations of royalties in this infinitely repeated game. With some vertically integrated and some non-integrated firms the game is asymmetric. Therefore, there is no reason to assume that the players will coordinate on an equilibrium with symmetric royalty rates.

C. Non-linear and Discriminatory Royalties

Firms may also use non-linear royalties such as two-part tariffs. If cross-licensing agreements can be written, this does not change the analysis. The parties can set the linear parts of the royalties such that the monopoly outcome is implemented and use the fixed fees to redistribute the surplus among themselves. The same is true if firms cooperate through an implicit contract in an infinitely repeated game.

Non-linear royalties are more interesting in the one-shot interaction model without cross-licensing agreements of Section 3. Consider the case of non-integration first. Suppose that each upstream firm $u \in \{1,...,n\}$ offers a two-part tariff consisting of a fixed royalty R_u and a linear royalty r_u that has to be paid for each unit of downstream production. Consider any given and fixed sum of linear royalties $r = \sum_{u=1}^{n} r_u$. Given r each downstream firm will earn the same quasi-rent $QR(r,m) = [P(Q^{NI}(m,r)) - k - r] \cdot q^{NI}(r,m)$ in the Cournot equilibrium of the downstream market. This quasi-rent can be captured through the fixed royalties of the upstream firms. If the sum of the fixed royalties of the other upstream firms is smaller than the quasi-rent of each downstream firm, firm u has an incentive to raise its fixed royalty until $\sum_{u=1}^{n} R_u = QR(r,m)$. Thus, upstream firms can extract the

entire surplus from downstream firms, but there are multiple equilibria: Any vector of fixed royalties that sums up to $QR(r,m)$ is an equilibrium.

What linear royalties will be chosen on the upstream market? When a non-integrated upstream firm raises its linear royalty r_u it will not only consider the effect on its own upstream profit, but also the effect on the profits of the downstream firms. Suppose that a reduction of r_u increases downstream profits. Then firm u can lower r_u and raise R_u, so as to fully extract the additional profits of downstream firms. Therefore, with two part tariffs the double mark-up problem disappears.

However, the complements problem remains. Upstream firms do not internalize the external effect of r_u on all other upstream firms. Therefore, royalties will be higher than in the case with cross licensing.

Consider now the case of vertical integration. If there are at least two vertically integrated firms, there is no symmetric pure strategy equilibrium. To see this suppose that there is an equilibrium in which all firms $i \in \{1,...,n\}$ charge (r_i, R_i). First of all, it must be the case that the fixed royalties extract the quasi-rents of the downstream market. Otherwise, each firm would have an incentive to further raise its fixed royalty. But then, all vertically integrated firms are just indifferent whether or not to produce downstream. Suppose now that firm i further increases r_i and/or R_i. This does not affect the costs of firm i but it raises the costs of its downstream rivals. Therefore, the other firms would now make losses on the downstream market and some of them may exit with positive probability which benefits firm i. Therefore, firm i always has an incentive to deviate from the proposed equilibrium candidate, which shows that a symmetric, pure strategy equilibrium does not exist. The reason is the "raising-one's-rivals'-cost" effect.

As we have seen in Section A, vertically integrated firms can deal with the "raising-one's-rivals'-cost" effect by writing a cross-licensing agreement. However, even in this case they have an incentive to discriminate against non-integrated downstream firms in order to jointly monopolize the downstream market. Non-

integrated upstream firms do not have this incentive. To the contrary, they benefit from more downstream competition because it increases downstream quantities and therefore their royalty income.

D. Investments in Research and Development

So far we assumed that all the relevant technologies and patents exist already and that investment costs are sunk and do not matter for the allocation of royalty income. Let us now consider stage 0, at which the upstream firms have to decide on whether or not to invest into the research and development of the required technologies. Suppose for simplicity that there are n firms indexed by $i \in \{1,...,n\}$ and that each firm is dealing with one piece of technology. Each firm has to decide whether to invest into this technology at cost I_i, in which case the technology will be developed and the firm receives a patent for it, or whether not to invest in which case the technology is not developed and a different standard will be adopted without the contribution of firm i. If all firms invest and all the pieces of technology are developed, the downstream good can be produced. Otherwise the good cannot be produced.

Suppose that it is efficient that all firms carry out their investments and that the profits that can be made with the production of the good are sufficient to cover the sum of the investment costs. In order to induce all firms to invest, they have to expect to get a share of future profits that is at least as large as their investment costs. Ideally, the parties would write a contract on how to split the future surplus before carrying out the investments. For example, the firms could enter a cross-licensing agreement that covers future patents or specifies a mechanism on how to set royalties in the future. Note that the investment costs I_i may differ substantially across firms. This has to be reflected in the cross licensing agreements to induce all firms to invest.

If it is impossible to write such a contract, for example because it would have to relate to innovations that have not yet been made or because it not yet clear how high the investment costs of each firm will be, then the parties could rely on an

implicit contract that is sustained as the equilibrium of an infinitely repeated game. As we have shown in Section 4.B, there are many equilibria in the infinitely repeated game with different allocations of royalties. Which equilibrium is going to be played could depend on the investments that the parties carried out at stage 0. Those parties who had to invest more than others could get a larger share of the monopoly profit in order to reward them for their investment efforts. Thus, very different royalties across firms may be necessary and natural reflection of different investment costs.

V. CONCLUSIONS

This paper has presented a simple model of the interactions between upstream firms selling perfect complements and downstream firms requiring all of the upstream inputs before they are able to manufacture their products. We have modelled various competitive and cooperative structures upstream and downstream and find the following main results.

- First, when IP holders act non-cooperatively and there is competition downstream, royalty rates may be greater in a vertically integrated industry than in an otherwise identical non-vertically integrated industry. If vertically integrated and non-integrated firms coexist, the royalty rate charged by a non-integrated IP holder can be lower than the rates charged by its vertically integrated counterparts. This is because the vertically integrated companies have an incentive to raise the royalty rates charged to third party, downstream firms so as to raise their costs and gain a competitive advantage against their downstream rivals.
- Second, though cross licensing agreements between vertically integrated companies may lead to lower royalty rates for the club of vertically integrated companies, they do not eliminate the raising rivals' cost distortion with respect to non-integrated downstream competitors. Furthermore, we find that if, under reasonable assumptions, a club of vertically integrated companies and some non-integrated companies engage in cross-licensing agreements to maximise their

joint profits, the royalty rates charged by the non-integrated upstream firms may well be higher than the ones charged by the integrated companies. However, the high rate of the non-integrated firm cannot be regarded as "excessive" as the cumulative royalty rate under this asymmetric equilibrium is identical to the equilibrium cumulative royalty rate when royalty rates are required to be symmetric.

- Third, the same result holds if firms collude in an infinitely repeated game. If firms are required to charge symmetric royalties, there is a conflict of interest between integrated and non-integrated firms. Integrated firms prefer low royalties in order to shift profits to the downstream market while non-integrated upstream firms prefer higher royalties in order to shift profits upstream.
- Fourth, if firms can use non-linear royalty contracts, there are always multiple equilibria. If firms are non-integrated, upstream firms will set non-linear royalty schemes so as to eliminate any vertical distortion, which will not be the case for vertically integrated firms, since they have an incentive to raise-rivals' costs.
- Finally, if the upstream firms had different costs to develop their technologies, this could be reflected in different royalties, and this asymmetry in royalties would be efficient.

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