2001

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Working Paper Series

Centre for Public Policy Studies

No. 111 (5/01) CPPS

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Samiran Banerjee and Ping Lin*

March 8, 2001

Abstract

We analyze the incentives for cost-reducing R&D by downstream firms in a two-tier market structure. Downstream R&D increases the demand for an input, thereby allowing the upstream firm to raise the input price. While it lowers the benefit of R&D to a downstream firm, such a price adjustment by the input supplier leads to a higher production cost for all rival firms. Due to this "raising rivals' cost" effect, a downstream oligopolist may invest more in R&D than does a downstream monopolist, a phenomenon that does not occur in a purely horizontal setting. Fixed-price agreements under which the input price remains unchanged in response to downstream R&D promote innovation by eliminating the opportunistic behavior of the input supplier. In general, the incentive for downstream R&D is positively related to input pricing rigidity

Keywords: Vertical R&D, Raising rivals' cost, fixed-price contract

JEL Numbers: L13, L22, O31

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1 Introduction

There is by now a huge body of literature dealing with various aspects of innovative R&D[1] with much attention focused on horizontal R&D in industries where firms are competitors on the product market. In this paper we extend our understanding of horizontal R&D by considering innovations in vertically related industries.

In markets that involve two tiers of producers such as upstream input suppliers and downstream manufacturers, innovations by downstream producers inevitably affect upstream suppliers. For example, cost-reducing R&D by automobile makers enable them to lower prices and sell more cars, which leads to the increased purchase of auto parts. Innovative activities by a computer retailer like Dell brings benefits to suppliers of components (such as chips) and complementary products (such as software), in addition to themselves. It is obvious that innovations by downstream producers will lead to increased demand for the inputs they use in their production, which is beneficial to the input suppliers.[2] Taking this as our point of departure, we study how this affects the R&D incentive of downstream producers.

We find that the increased demand for the input may allow suppliers to increase the input price while selling more of the input. We derive conditions under which this price increase takes place for general demand functions for the final product: essentially, cost-reduction downstream must make the derived demand curve for the input steeper. We then show that this price increase has two opposing effects on the R&D incentive of a downstream producer. While the higher input price offsets some of the cost reduction of the downstream firm from the R&D (a negative incentive effect), the

[1] See Reinganum (1989) for a detailed survey.

[2] See Lee (1996) for an analysis of this demand-pull effect of the investment by Japanese machine tools users on the tool suppliers.

increase in input price applies to all the other downstream firms as well. Therefore the R&D by the downstream firm indirectly raises the production cost of its competitors (a positive incentive effect). We show that due to this raising rivals' cost (RRC) effect, downstream firms may have a stronger incentive to do R&D when the degree of downstream competition is low. In particular, we show that downstream oligopolists each invest more in R&D than a downstream monopoly, provided the number of firms is not too large (fewer than 6 in the case of linear demand). Of course such a scenario could never arise in standard horizontal R&D settings.

The tendency for the upstream suppliers to raise the input price after the downstream producers have conducted their R&D can be viewed as a type of opportunistic behavior on the part of the suppliers. One way to overcome this negative incentive effect is for the suppliers and the manufacturers to sign a fixed input price contract. Under this type of contract, the suppliers agree not to change the input price in response to downstream R&D, a kind of long-term input price agreement. We show that while this type of contract eliminates the RRC incentive for R&D, the net effect is that firms are more innovative than under the floating price arrangement. Our results shed light on why vertically related firms may often engage in long term contractual relationships regardless of other considerations.

To highlight the positive relationship between input pricing rigidity and the incentive for downstream R&D, as well as to isolate the RRC effect, we consider the case where the input supplier is able to price discriminate among downstream producers. We show that such increased flexibility in input pricing by the upstream supplier further hinders the downstream R&D incentive for R&D, relative to the uniform but floating price arrangement. Under price discrimination, the monopoly supplier can raise the input price for an innovating downstream producer without having to raise the prices of its other rival firms. Therefore, the RRC effect is absent under price discrimination and consequently, the equilibrium R&D level is lower than under uniform pricing.

Our paper is related to several branches of the industrial organization literature. First, it contributes to the literature on horizontal R&D which has received a great deal of attention in the past two decades. This strand typically examines the R&D incentives of firms competing in the product market, abstracting from the upstream suppliers of inputs. In such a pure horizontal R&D set-up, a firm's cost-reducing investment enables it to steal market share from its rivals without affecting their cost structures. The main questions addressed here have included the impact of the degree of product market competition on firm R&D incentives, the effect of R&D cooperation, the implication of R&D spillovers, and the design of public policy to best induce welfare improving innovative activities by private firms. One of the well-understood results in this literature is that (for non-drastic innovations) firms' R&D investment levels decline as the number of competitors increase because increased competition erodes the return to innovation. Our paper is among the first to extend the R&D literature into a vertical setting by focusing on the effect of a firm's R&D investment on its rivals channelled through the reactions of an upstream supplier. Our analysis identifies the RRC effect of R&D because of which a downstream duopolist invests more in R&D than does a downstream monopoly.

Secondly, the general idea of a firm obtaining a competitive advantage through strategic actions that can raise rivals' costs is not new in the industrial organization literature. For example, Salop and Scheffman (1983) argue that a firm can raise the costs of production of its rivals by means of inducing supplier group boycotts, promoting industry-wide labor unionization, lobbying for more government regulations, and so on. In models of vertical integration and foreclosure, Salinger (1988) and Ordover, Saloner and Salop (1990) show that a downstream firm may strategically acquire an input supplier with the purpose of reducing upstream competition and hence raising the input price for its downstream competitors. In this paper we show that an RRC effect also exists when downstream firms engage in cost-reducing R&D, where the effect is channelled through the increased demand for the input resulting from downstream R&D.

Our paper is also related to the study of investment incentives of firms in the bilateral ‘hold-up’ problem.[3] One fundamental insight from this line of research is that in the presence of asset specificity, firms who are about to form a bilateral partnership tend to underinvest as each fears the possible post-investment exploitation by the other party. Two ways to overcome such “opportunistic behavior” are for the parties to form a single firm (through vertical integration, for example) or to contract through a third party. Our analysis of fixed-price contracting is very much in the same spirit of mitigating the “opportunistic behavior” of the upstream firm.

Fixed-price arrangements in the context of R&D have received some attention recently from McLaren (1999) who contrasts them with informal agreements (“handshakes”) between upstream suppliers and downstream customers. He shows that fixed price contracting encourages autonomous innovation by the upstream supplier, but handshake arrangements are better for promoting joint innovation by both the supplier and the customer. Our focus however is different: we look exclusively at downstream R&D and consider the role of fixed-price contracts in mitigating the RRC effect.[4]

Finally, some recent studies on R&D incorporate a two-tier structure but focus on research questions that are different from ours. Steurs (1995) and Inkmann (1999) extended the horizontal R&D literature by adding an

[3]See Williamson (1975) and Klein (1988), for example.

[4]The RRC effect is absent in McLaren’s model because the output of each downstream producer is normalized to unity so that the demand for the input is independent of downstream research investment.

upstream market into the model of d'Asprémont and Jacquemin (1988) and explore the effects of intra- and inter-industry spillovers. Stefanadis (1997) analyzes the relationship of upstream R&D and vertical foreclosure, and shows that an upstream supplier has an incentive to "capture" a downstream user in order to reduce the customer base for another upstream firm's R&D. In a model of vertical research joint ventures (VRJVs), Banerjee and Lin (2001) look at the incentives of upstream and downstream firms in forming VRJVs and examine the equilibrium VRJV size under different cost-sharing rules.

The rest of the paper is organized as follows. In Section 2, we look at general demand and derive the sufficient condition for downstream R&D to increase the input price charged by the upstream supplier. In Section 3, we analyze the RRC effect of R&D in the linear demand set-up and show how the RRC effect and the equilibrium R&D investment vary with the number of firms. Section 4 shows that a fixed-price contract can serve as a means of mitigating the opportunistic behavior of upstream suppliers and thus promote downstream R&D. Section 5 considers differential pricing contracts and Section 6 concludes.

2 Sufficient Conditions for Raising the Input Price

Consider a two-tier industry with one upstream firm, U, and n downstream firms indexed by D_j, $j = 1, ..., n$. The upstream firm supplies an intermediate good to the downstream firms whose output of the final product is $\{q_j\}$. The cost of production for the upstream firm is normalized to zero. The final good is produced with a fixed-coefficient technology (one unit of final product requiring exactly one unit of the input), with the marginal cost of transforming the intermediate good into the final good being c_j. Let w be the price of the intermediate good. Thus, the marginal cost of producing the final good for downstream firm D_j is $w + c_j$. The inverse demand for the final good is given by $p = p(Q)$ where $p' < 0$ and $Q = \sum_{j=1}^{n} q_j$. The downstream firms compete in Cournot fashion in the market for the final product.

Given the input price w set by the upstream supplier, firm D_j maximizes

$$p(Q)q_j - (w + c_j)q_j.$$

The first order condition is

$$p(Q^*) + p'(Q^*)q_j^* = w + c_j, \qquad j = 1, \ldots, n \tag{1}$$

where $Q^* = \sum_{j=1}^{n} q_j^*$. The second order sufficient condition for a maximum is $2p'(Q^*) + p''(Q^*)q_j^* < 0$. The system of equations in (1) determine the Cournot equilibrium output levels in the downstream market. Summing up these first order conditions over all j we get

$$np(Q^*) + p'(Q^*)Q^* = nw + \sum_{j=1}^{n} c_j \tag{2}$$

which implicitly defines the derived demand for the input $Q^* = Q^*(w, c_1, \ldots, c_n)$. Differentiating (2) with respect to c_j and w yields

$$\frac{\partial Q^*}{\partial c_j} = \frac{1}{(n+1)p'(\cdot) + p''(\cdot)Q^*} < 0 \quad \text{and} \quad \frac{\partial Q^*}{\partial w} = \frac{n}{(n+1)p' + p''(\cdot)Q^*} < 0, \tag{3}$$

where the sign follows from summing across the second order conditions for all n downstream firms. Since $\frac{\partial Q^*}{\partial c_j} < 0$, it implies that cost-reducing R&D by any downstream firm raises the demand for the input.

The upstream firm then maximizes its profit $w \cdot Q^*(w, c_1, \ldots, c_n)$ by choosing the input price w, yielding the first order condition

$$Q^* + w^* \frac{\partial Q^*}{\partial w} = 0. \tag{4}$$

Equation (4) implicitly defines the equilibrium input price $w^* = w^*(c_1, ..., c_n)$. To see the impact of downstream R&D on the equilibrium input price, we differentiate (4) with respect to c_j and rearrange terms, yielding

$$\frac{\partial w^*}{\partial c_j} = \frac{\frac{\partial Q^*}{\partial c_j} + w^* \frac{\partial^2 Q^*}{\partial w \partial c_j}}{-\left[2\frac{\partial Q^*}{\partial w} + w^* \frac{\partial^2 Q^*}{\partial w^2}\right]}. \tag{5}$$

The denominator is positive by the second order condition of U's maximization problem. Since $\frac{\partial Q^*}{\partial c_j} < 0$ from (3), a sufficient condition for $\frac{\partial w^*}{\partial c_j}$ to be negative is $\frac{\partial^2 Q^*}{\partial w \partial c_j} \leq 0$. From (3), we get

$$\frac{\partial^2 Q^*}{\partial w \partial c_j} = \frac{(n+2)p''(\cdot) + p'''(\cdot)Q^*}{[(n+1)p'(\cdot) + p''(\cdot)Q^*]^2}\left(-\frac{\partial Q^*}{\partial w}\right)$$

which is non-positive if $(n+2)p''(\cdot) + p'''(\cdot)Q \leq 0$ at Q^*. Therefore, we have the following result.

Proposition 1 *For general demand function $p(Q)$ with $p' < 0$, a reduction in a downstream firm's marginal cost will cause the input price to go up if $(n+2)p''+p'''Q \leq 0$ at the equilibrium Cournot quantity $Q^*(w^*, c_1, c_2, \ldots, c_n)$.*

The condition that $\frac{\partial^2 Q}{\partial w \partial c_j}$ is non-positive simply says that downstream R&D makes the derived demand *steeper*. Note that this condition holds in the special case of linear demand $p = a - Q$ since $p'' = p''' = 0$.

It is useful to contrast our vertical two-tier market structure with the standard one-tier horizontal R&D setting. In the latter, a firm's cost-reducing R&D investment serves the sole purpose of increasing its cost advantage over its rivals by lowering its cost of production. In our model, however, R&D by a downstream firm has an additional "strategic effect" on its competitors: downstream R&D by increasing the demand for the intermediate good could result in a higher input price for all the downstream firms. Although the increased input price partially offsets the cost-reduction of the firm that does R&D, it also provides this firm with a new incentive for downstream R&D, namely to raise its rivals' costs, an effect which is absent in standard horizontal settings. Thus R&D by a downstream producer not only confers on it a cost advantage relative to its rivals, but it additionally raises its rivals' absolute cost through the input price adjustments in the upstream market. In the next section, we explore this raising rivals' cost (RRC) effect when the demand for the final product is linear to see how this affects a downstream firm's incentive for R&D.

3 Raising Rivals' Cost Incentive for R&D: The Case of Linear Demand

Suppose the inverse demand for the final good is linear: $p = a - Q$, $a > 0$. The marginal cost of transforming the input good into the final good for firm D_j is $c - y_j$, where y_j is the cost-reduction as a result of R&D undertaken by firm D_j. For simplicity, assume that the R&D cost is given by γy_j^2. Throughout the paper, it is assumed that $\gamma \geq 1$ so that the R&D cost function is convex enough to guarantee the validity of the second order conditions for R&D maximization problems. As in the previous section, the downstream firms make R&D decisions simultaneously. Then the input supplier sets the price of the input and the downstream firms compete in the market for the final product. We solve the equilibrium R&D investment using the standard backward induction procedure. In this simple set-up, we will be able to see clearly how the RRC effect influences firms' R&D decisions.

Given their R&D decisions and the price of the input, w, the downstream firms compete in Cournot fashion, resulting in an output level of

$$q_j = \frac{a - c - w + (n+1)y_j - \sum_{k=1}^{n} y_k}{n+1} \tag{6}$$

for any $j, k = 1, 2, \ldots, n$, $j \neq k$. The derived demand for the input is thus

$$Q = \sum q_j = \frac{n(a - c - w) + \sum y_j}{n + 1},$$

or equivalently,

$$w = a - c + \frac{1}{n} \sum y_j - \frac{n + 1}{n} Q.$$

The upstream firm simply sets the input price at the monopoly level

$$w^* = \frac{a - c + \sum y_j / n}{2}. \tag{7}$$

Substituting this into the inverse demand function for the input, we get the equilibrium aggregate output

$$Q^* = \frac{n\left(a - c + \sum y_j / n\right)}{2(n + 1)}. \tag{8}$$

Before proceeding further, it is useful now to note that firm D_j's overall marginal cost is

$$w^* + c - y_j = \frac{a + c + \sum y_k / n - 2y_j}{2},$$

implying that

$$\frac{\partial(w^* + c - y_j)}{\partial y_j} = -\frac{2n - 1}{2n} \quad \text{and} \quad \frac{\partial(w^* + c - y_j)}{\partial y_k} = \frac{1}{2n} \text{ for } k \neq j,$$

a result summarized in the lemma below.

Lemma 1 *A unit reduction in firm D_j's marginal transformation cost decreases its overall marginal cost by $1 - \frac{1}{2n}$ and raises each rival firm's overall marginal cost by $\frac{1}{2n}$.*

Lemma 1 indicates the existence of the RRC effect and how this effect depends on the degree of downstream competition. As n rises, each individual downstream firm becomes smaller relative to the industry (its Cournot output declines). So a drop in its unit cost will not shift the demand for the input as much. Thus, the increase in the input price is smaller, resulting in a weaker RRC effect on its rival firms.

Substituting for w^* from equation (7) into equation (6), we get the downstream Cournot quantities

$$q_j = \frac{1}{2(n+1)}\Big[(a-c) + 2\Big\{(n+1)y_j - \sum y_k\Big\} - \sum y_k/n\Big]$$

and profits

$$\pi_j^D = [a - \sum q_k - (w^* + c - y_j)]q_j = (q_j)^2.$$

At the R&D stage, each downstream firm chooses y_j to maximize $\pi_j^D - \gamma y_j^2$. Solving the first order condition and imposing the symmetry condition $y_j = y^*$, we obtain the equilibrium R&D level for each downstream firm[5]

$$y^*(n) = \frac{a-c}{\gamma H(n) - 1},$$

where

$$H(n) \equiv \frac{4(n+1)^2 n}{2n^2 - 1}.$$

To illustrate the RRC effect on firm incentive to conduct R&D, compare the case of a successive monopoly ($n = 1$) with that of a downstream duopoly ($n = 2$). We have

$$y^*(1) = \frac{a-c}{16\gamma - 1} \quad \text{and} \quad y^*(2) = \frac{a-c}{\frac{72}{7}\gamma - 1}\ .$$

Therefore, $y^*(2) > y^*(1)$; a downstream duopolist invests more in R&D than does a downstream monopolist. If $n = 3$, then $H(3) = \frac{192}{17} > \frac{72}{7}$. Thus $y^*(3) < y^*(2)$. It can be easily shown that $y^*(n)$ further decreases with n for all $n \geq 3$ and that the following result holds.

[5] The second order condition for the R&D maximization problem is $\frac{(2n^2-1)^2}{4n^2(n+1)^2} \leq \gamma$. Since the lefthand side is always less than 1, the assumed condition $\gamma \geq 1$ is sufficient to fulfill this requirement.

Proposition 2 *If $\gamma \geq 1$, then $y^*(n)$ increases as n goes from 1 to 2 and then decreases with $n > 2$. In particular, $y^*(n) > y^*(1)$ for $n < 6$.*

Proof. Ignoring that n is an integer, $H'(n)$ has the same sign as $2n^3 - 2n^2 - 3n - 1$, which is positive if and only if is $n \geq 2$. The second part of the proposition can be proven by noting that $y^*(n) > y^*(1)$ if and only if $H(n) < 16$. This latter inequality is equivalent to $n^3 - 6n^2 + n + 4 < 0$, which holds if and only if $n < 6$. ∎

Proposition 2 can be understood as follows. An increase in n impacts R&D in two ways. First, increased competition in the final product market reduces the output for each downstream firm and erodes its profits, which tends to reduce their incentive for cost-reducing R&D. This effect leads to a monotonic decline of equilibrium R&D with the number of producers in the usual horizontal setting.[6] In our two-tier model however, there is a second and opposing factor, the RRC effect which is unique to a vertical setting, that promotes the initial increase of equilibrium R&D as we go from a downstream monopoly (where the RRC effect is absent) to a downstream duopoly. Indeed, the RRC incentive for downstream R&D is quite strong: compared to the case of downstream monopoly, downstream oligopolists invest more in R&D than a monopolist as long as $n < 6$.

At the symmetric equilibrium, the profit of each downstream firm net of R&D cost is

$$\begin{aligned} \pi_j^D - \gamma(y^*)^2 &= \frac{(a - c + y^*)^2}{4(n+1)^2} - \gamma(y^*)^2 \\ &= \frac{(\gamma H y^*)^2}{4(n+1)^2} - \gamma(y^*)^2 = \left[\frac{\gamma^2 H^2}{4(n+1)^2} - \gamma\right](y^*)^2. \end{aligned} \tag{9}$$

[6]See d'Asprémont and Jacquemin (1988), and Suzumura (1992) for example.

Noting (8), the profit of the upstream supplier is,

$$\pi^U = w \cdot Q = \frac{n\left(a-c+y^*\right)^2}{4(n+1)} = \frac{n\gamma^2 H^2 (y^*)^2}{4(n+1)}. \tag{10}$$

4 Fixed-Price Contract

Although ex post it is optimal for the upstream firms to raise the input price after the downstream firms have completed their R&D projects, such a price adjustment obviously hurts the R&D incentive of the downtream firms. Since reduced downstream R&D means lowered demand for the input, it is in the interest of the upstream suppliers ex ante to find ways to alleviate or to eliminate the 'opportunistic behavior' of raising the input price. Suppose the firms can write a contract wherein the input price cannot be changed after R&D, i.e., the input price is chosen before R&D is undertaken and stays fixed thereafter. This type of arrangement can be viewed as a long-term contractual relationship whereby the upstream and the downstream firms commit to a prespecified input price even if the downstream firms increase the quantity of the input purchased from the supplier. In this section, we show that this type of arrangement promotes R&D by eliminating the 'opportunistic behavior' on the part of the supplier. While the arguments are made in the case of linear demand, it should be clear that the intuition carries over to more general demand as well.

Under a fixed-price contract, the price level for the input is chosen first and remains fixed forever. Given w, the downstream firms simultaneously choose their R&D investment levels, y_j. Given w and these R&D levels, Cournot competition downstream yields the following quantity for firm D_j (same as equation (6)):

$$q_j = \frac{a-c-w+ny_j-\sum_{k\neq j} y_k}{n+1}.$$

The profit of D_j is then

$$\pi_j^D = (p - w - c + y_j)q_j = (q_j)^2 .$$

At the R&D stage, firm D_j maximizes $\pi_j^D - \gamma y_j^2$, taking w as given. The corresponding first order condition is

$$2n\left(\frac{a - c - w + ny_j - \sum_{k\neq j} y_k}{(n+1)^2}\right) = 2\gamma y_j. \tag{11}$$

The symmetric equilibrium R&D level is thus

$$y(w) = \frac{a - c - w}{\gamma(n+1)^2/n - 1}. \tag{12}$$

As is to be expected, the downstream R&D level depends negatively on the level of input price.

The total output corresponding to the symmetric R&D equilibrium is

$$\begin{aligned} Q(w) &= nq_j = \frac{n}{n+1}\left[\frac{1}{\gamma(n+1)^2/n - 1} + 1\right](a - c - w) \\ &= \frac{\gamma(n+1)(a - c - w)}{\gamma(n+1)^2/n - 1}. \end{aligned}$$

Anticipating the relationship given by $y(w)$, the upstream supplier chooses an input price w to maximize its profit $w \cdot Q(w)$. The solution to this problem is

$$w_f = (a - c)/2. \tag{13}$$

Substituting this into equation (12), we get the equilibrium R&D level under the fixed-price contract:

$$y_f(n) \equiv y(w_f) = \frac{1}{2} \cdot \frac{a - c}{\gamma(n+1)^2/n - 1}.$$

It is then easily seen that $y_f(n) > y^*(n)$ because $2n/(2n^2 - 1) > 1/n$.

Proposition 3 *Fixed-price contract by a upstream monopolist promotes downstream R&D, i.e.,* $y_f(n) > y^*(n)$ *for all* n *and* $\gamma \geq 1$.

Under the fixed-price contract, the upstream supplier commits not to raise the input price after downstream firms conduct cost-reducing R&D. This encourages R&D by the downstream producers by increasing the direct benefits of innovation to those producers. Although the RRC incentive for R&D (which is conducive to downstream innovation) is also eliminated, the positive direct effect is so strong that the downstream producers end up investing more in R&D under a fixed-price contract.

From equation (11), each downstream firm's net profit under the fixed price contract can be calculated to be

$$\begin{aligned} \pi_j^D - \gamma y^2 &= (q_j)^2 - \gamma y^2 = \left[\left(\frac{n+1}{n}\gamma\right)^2 - \gamma\right] \cdot [y(w^*)]^2 \\ &= \left[\left(\frac{n+1}{n}\gamma\right)^2 - \gamma\right] \cdot \left[\frac{1}{2}\frac{a-c}{\gamma(n+1)^2/n-1}\right]^2. \end{aligned} \tag{14}$$

The profit of the upstream firm is

$$\pi^U = w^* \cdot Q(w^*) = \left[\frac{(a-c)^2}{4}\right]\left[\frac{\gamma(n+1)}{\gamma(n+1)^2/n-1}\right]. \tag{15}$$

Can the R&D-stimulating fixed price contract be beneficial to *all* firms including the upstream firm, relative to the case analyzed in Section 3? Intuitively, the downstream firms should be better off under a fixed contract as the input price cannot increase after their R&D projects are completed. There are two opposing effects at work for the upstream firm. First, firm U's profit tends to go down as it cannot raise input price to take advantage of the increased input demand. Second, because downstream producers invest more in R&D and thus buy more of the input from it, the upstream supplier's profit tends to increase. The net effect on the upstream firm therefore depends on which of these two effects is stronger. Unfortunately, algebraic complexity does not permit analytical results regarding the ranking of firm profits under fixed contract (equations (14) and (15)) versus when the input price can respond to downstream R&D (equations (9) and (10)). But numerical simulations reveal that the second effect always dominates the first so that fixed input price contract increases the profits of both the upstream and the downstream firms.

Proposition 4 *Assuming that the demand for the final product is linear and the R&D cost function is γy^2, a fixed price contract by an upstream monopoly makes all firms better off for all $n > 1$ and $\gamma \geq 1$.*

Since industry output increases with the R&D level, consumers also benefit with the increased innovation. Thus, the fixed-price contract analyzed above improves social welfare as well.

5 Price Discrimination

In this section, we consider the case that the upstream monopolist is able to charge each downstream producer a different price w_j. The upstream supplier enjoys the most freedom in adjusting the input price under price discrimination—although it also has the flexibility to change the input price under the floating price arrangement considered in Section 3, the input supplier in that case must charge all its n customers a uniform price. We make two points in this section. First, when the upstream supplier engages in price discrimination, the RRC effect is absent. As a result, equilibrium R&D monotonically decreases with the number of downstream firms, as is the case in a horizontal R&D settings. Secondly, we show that the equilibrium R&D level under price discrimination is even lower than that under the uniform floating price arrangement. This, together with the result for fixed-price contract, tells us that price flexibility by the upstream supplier discourages downstream R&D.

Given the input price vector $\mathbf{w} = (w_1, w_2, ..., w_n)$ and R&D investment vector $\mathbf{y} = (y_1, y_2, ..., y_n)$, downstream Cournot output levels are

$$q_j(\mathbf{w}, \mathbf{y}) = \frac{a - (n+1)(w_j + c - y_j) + \sum_{k=1}^{n}(w_k + c - y_k)}{n+1}. \tag{16}$$

Thus $q_j(\mathbf{w}, \mathbf{y})$ is the derived demand for the input by firm D_j, which, as is to be expected, depends on the cost conditions of its rival firms.

The upstream firm then chooses the vector of input prices $\mathbf{w}$ so as to maximize $\sum_{j=1}^{n} w_j \cdot q_j(\mathbf{w}, \mathbf{y})$. The first order conditions are

$$\frac{a - (n+1)(w_j + c - y_j) + \sum_{k=1}^{n}(w_k + c - y_k)}{n+1} - \frac{n}{n+1} w_j + \sum_{k \neq j} w_k \frac{\partial q_k}{\partial w_j} = 0$$

which simplifies to

$$a - c + (n+1)y_j - \sum_{k=1}^{n} y_k - 2(n+1)w_j + 2\sum_{k=1}^{n} w_k = 0. \tag{17}$$

Summing up these first order conditions over j, we get

$$2\sum_{j=1}^{n} w_j = n(a-c) + \sum_{j=1}^{n} y_j.$$

Substituting this into (17) yields the optimal prices for the upstream supplier:

$$w_j = \frac{a - c + y_j}{2}. \tag{18}$$

Here downstream R&D by firm D_j raises its own input price only. The input prices for other rival firms are independent of D_j's R&D investment, and consequently the RRC effect is not present under price discrimination.[7]

[7]The intuition for this is as follows. From (16), we have $\frac{\partial q_j}{\partial y_j} = \frac{n}{n+1}$ and $\frac{\partial q_k}{\partial y_j} = -\frac{1}{n+1}$, for $k \neq j$. Thus, cost-reducing R&D by a downstream firm D_j increases its derived demand for the input and decreases the derived demand for the input by all its rival firms. This

Substituting the optimal input prices into the expressions for $q_j(\mathbf{w}, \mathbf{y})$ and after some simplification, we get

$$q_j(\mathbf{y}) = \frac{a - c + ny_j - \sum_{k \neq j} y_k}{2(n+1)}.$$

The corresponding profit of firm D_j is thus

$$\pi_j^D = \left[\frac{a - c + ny_j - \sum_{k \neq j} y_k}{2(n+1)}\right]^2.$$

At the R&D stage, firm D_j chooses y_j to maximizes it profit $\pi_j^D - \gamma y_j^2$ yielding the following first order condition:

$$\frac{a - c + ny_j - \sum_{k \neq j} y_k}{4(n+1)^2} \cdot n = \gamma y_j$$

The symmetric R&D equilibrium level under price discrimination is thus given by

$$y_d(n) = \frac{a - c}{4\gamma(n+1)^2/n - 1}.$$

It can be easily seen that y_d is smaller than y^* because $n^2/(2n^2 - 1) < 1$. Combining this with the result in Proposition 3, we have:

Proposition 5 *The equilibrium R&D level is highest under the fixed-price contract and lowest under price discrimination, i.e.,* $y_d(n) < y^*(n) < y_f(n)$.

One can also compare the prices under the three scenarios we have considered. From equations (7), (13), (18) and the above proposition, we obtain

suggests that following R&D investment by D_j, the upstream monopoly will raise the input price w_j and lower all w_k, $j \neq k$. However, if the upstream firm reduces input prices for firms other than D_j, the derived demand by firm D_j declines, thus undermining the effort of the U-firm to take advantage of D_j's increased demand for the input. In the linear demand set-up, it turns out that the U-firm, in maximizing its overall profits, chooses not to adjust other input prices in response to D_j's R&D.

that the input price is the lowest under the fixed price contract and highest under uniform pricing. The upstream firm charges the lowest input price under the fixed contract because it cannot respond to the increase in the demand for the input caused by downstream R&D. That input price is higher under uniform pricing than under price discrimination is a direct consequence of the fact that downstream firms invest more in R&D under uniform pricing, leading to a higher demand for the input. Further, since aggregate output is positively related to downstream R&D, we conclude from the above proposition that the price of the final product is lowest under the fixed price contract and highest under price discrimination.

The question of how price discrimination by an upstream input supplier affects downstream cost-reducing decisions was analyzed by DeGraba (1990). DeGraba considers the case of a downstream duopoly and shows that the downstream producers, who have two feasible technologies to choose from, will select a technology with a higher marginal cost when the input supplier price-discriminates than when it charges a uniform price. While DeGraba was concerned with the welfare effects of price discrimination, we in this section simply emphasize the point that additional freedom on the part of the supplier's price-setting behavior further reduces the R&D incentive of the downstream producers by removing the RRC effect.

6 Conclusions

The insights from the analysis of R&D among firms in a vertical relationship add considerably to those arising from the study of horizontal R&D alone since the latter do not capture the interaction between the market tiers. First, firms may only gain a relative cost advantage over their rivals under horizontal R&D but with the introduction of the supplier-buyer relationship, R&D by a firm may also raise their rivals' absolute costs of production by increasing the per-unit price they have to pay for it. Consequently, increased downstream competition may lead to a greater investment in R&D downstream due to the increase in rivals' cost. We show that this is likely to occur when upstream firms have sufficient market power over the price of the intermediate good.

Second, although it is optimal for the upstream supplier to raise the input price post-R&D, such adjustment hampers the downstream firms' incentive to innovate in the first place. Reduced downstream R&D in turn hurts the upstream supplier. We show that a long-term contract between the supplier and the input buyers under which the input price is not allowed to change as downstream firms innovate has the effect of promoting innovation and benefiting firms at both levels of the market. Thus, fixed price contracts can not only be a means of controlling production costs downstream, but can also stimulate innovation downstream.

Our model with an upstream monopoly can be extended to one with an oligopoly upstream. While it does not change the fact that downstream R&D can increase the upstream input price by increasing the derived demand for the input, having competition at the upstream level could change the degree of the RRC effect. If there is enough competition among the input suppliers, a given increase in the derived demand for the input may not translate into a large increase in its price. We believe that the basic results continue to hold in a model with an oligopoly upstream as long as the number of input suppliers is not too big. Regarding the feasibility of a fixed-price contract, a coordination problem may arise when there are more than one upstream firms as to whether and how the input suppliers can fixe input prices. One arrangement could be the overt collusion among the input suppliers. As long as the suppliers can agree not to change input prices in response to downstream R&D, price cartel agreements among the suppliers (which are per se illegal under the antitrust laws) may potentially be welfare improving by encouraging downstream innovation.

One can also extend our analysis by adding R&D on the part of the upstream firm as well. In such a situation, R&D activities by upstream and downstream firms will be strategic complements and consequently increased R&D investment downstream will induce the upstream firm to invest more in R&D as well. We expect the basic results of our paper to hold in this extended setting as well.

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