Downstream R&D, Raising Rivals’ Costs, and Input Price Contracts

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Abstract

We analyze the incentives for cost-reducing R&D by downstream firms in a two-tier market structure. By increasing the demand for an input, downstream R&D allows the upstream firm to raise its input price. This lowers the benefit of R&D to a downstream firm but raises its rivals’ costs. As a result, a downstream oligopolist may invest more in R&D than a downstream monopolist, a phenomenon that is absent in a purely horizontal R&D setting. Fixed-price agreements (where the input price remains unchanged following downstream R&D) promote innovation by eliminating the opportunistic behavior of the input supplier and are welfare enhancing.

Key words: Vertical R&D, Raising rivals’ cost, Fixed-price contract

JEL classification: L13, L22, O31

1 Introduction

There is by now a large body of theoretical literature dealing with various aspects of innovative R&D focusing primarily on horizontal research in industries where firms are competitors on the product market.\textsuperscript{1} However, much

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\textsuperscript{1} The main questions addressed in this literature include the impact of the degree of product market competition on firm R&D incentives, the implication of R&D spillovers, the motives for and effects of R&D cooperation, and the design of public policy to best induce welfare-improving innovative activities by private firms. See Reinganum (1989) for a detailed survey.

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corporate R&D is conducted in a supplier-customer context. Vonortas (1997) and Harabi (1998) provide survey evidence from the US and Germany (respectively) of the importance of vertical innovation. In the well-documented studies of the automobile sectors in Japan and the United States (see Helper 1991, Lincoln et al. 1998 and McLaren 1999, among others), innovations by auto makers on the one hand and those by auto parts suppliers on the other are often closely coordinated. In this paper we extend the theoretical literature on horizontal R&D by considering innovations in vertically related industries. In particular, our objectives are to identify distinctive features of R&D competition in vertically related industries, and examine the role of upstream suppliers as well as input price contracts in influencing downstream R&D.

We consider a setting where there are two tiers of producers: upstream input suppliers and downstream manufacturers. In such markets, 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. In general, it is obvious that innovations by downstream producers will often lead to increased demand for the inputs they use in their production, which is beneficial to the input suppliers. 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 upward price adjustment occurs for general demand functions. 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 increase in input price indirectly raises the production cost of its competitors (a positive incentive effect). We show that due to this raising rivals’ cost (RRC) effect, 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, where R&D investment by a firm does not affect the cost level of its rival firms.

The tendency for the upstream supplier to raise the input price after the downstream producers have conducted their R&D can be viewed as a kind of opportunistic behavior on the part of the supplier. One way to overcome this negative incentive effect is for the supplier and the manufacturers to sign a fixed input price contract. Under this type of contract, the suppliers agree not

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2 See Lee (1996) for an analysis of this demand-pull effect of the investment by Japanese machine tools users on the tool suppliers.
to change the input price in response to downstream R&D. 3 We consider the case when an upstream supplier first chooses a price level for the input and then the downstream firms undertake cost-reducing R&D. While this type of fixed price contract eliminates the RRC incentive for R&D, we show that the fixed price contract promotes downstream R&D relative to the floating price arrangement. Because of this increased incentive for research, the downstream firms end up purchasing a much larger quantity of input while the upstream supplier earns a greater profit under the fixed price contract despite its inability to raise the input price. Our results shed light on why vertically related firms may often engage in long term contractual relationships regardless of other considerations. A fixed price contract also improves consumer welfare in our model, at least for linear demand, as it induces more downstream R&D, resulting in a larger equilibrium output and a lower price level of the final product.

Our paper contributes to the literature in several ways. First, by establishing that downstream R&D could lead to the upward input price adjustment under quite general demand conditions, we show that, in addition to some well-known inefficiencies (such as double marginalization), vertical market structures can also potentially hinder downstream R&D because the input suppliers have an incentive to extract rent from the research activity. Second, our paper is among the first to extend the theoretical 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 upstream suppliers. We identify the RRC effect of R&D which could lead a downstream oligopolist to invest more in R&D than a downstream monopoly. Third, our paper shows that the nature of input contracts could have a significant impact on downstream R&D: in the model we consider, fixed input price contracts eliminate the ‘opportunistic’ behavior of the input supplier and thereby promote downstream R&D. This also presents a testable empirical hypothesis that active downstream cost-reducing R&D ought to be correlated with long-term input contracts with price rigidity.

The tendency of an upstream firm to raise input price in response to downstream R&D may resemble the strategy of a price squeeze where an input supplier raises the input price in an attempt to extract economic rent from downstream firms. A vertically integrated firm could adopt a price squeeze strategy by increasing its input price while simultaneously decreasing the price.

3 For instance, toy manufacturers reward retailers like Toys ‘R’ Us for their significant role in expanding industry output — including product development, advertising and promotional services, market testing of new toys, as well as maintaining a sophisticated data management system that enables manufacturers to monitor sales of their products — by not raising the wholesale price of hit toys during the Christmas season (Carlton and Sider, 1999).
of the final product in an attempt to drive downstream rival firms out of business. However, the incentive to raise the input price in our model differs from a price squeeze in two important ways. First, an increase in the input price in our model is not a strategic move on the part of the supplier (say, out of the intention to drive out downstream competitors) — it is merely a profit-maximizing response to a change in market conditions, i.e., to an increase in the derived demand for the input arising from downstream R&D. Second, while a price squeeze in other settings generally benefits the firm that practices it, the ability to raise the input price in our model actually hurts the supplier by discouraging cost-reducing downstream R&D which in turn dampens the demand for the input. In fact, we show that the supplier in our model is better off using a fixed price contract instead of raising the input price.

The idea of a firm obtaining a competitive advantage through strategic actions that 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 lowering the level of 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. If a downstream firm is concerned about the effect of rising input price on its own R&D, it should also recognize the RRC effect on rival firms. It is in this sense that we believe the RRC effect is prevalent in R&D activities in vertically related markets.

Our paper is also related to the study of investment incentives of firms in the bilateral ‘hold-up’ problem. 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 instance) or to contract through a third party. Our

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4 Such a price squeeze strategy was alleged to have been used by Alcoa in the market for aluminum ingots — see United States v. Aluminum Company of America, 148 F.2d 416 (1945). Ordover, Sykes and Willig (1985) analyze the price squeeze behavior of a firm producing complementary goods as a means to extend its monopoly power in one market to another related market.

5 See Williamson (1975) and Klein (1988), for example.
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) extend the horizontal R&D literature by adding an 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, Banerjee and Lin (2001) look at the incentives of upstream and downstream firms in forming such ventures and examine their equilibrium sizes under different cost-sharing rules.

The rest of the paper is organized as follows. In Section 2, we analyze the RRC effect of R&D in a linear demand set-up and show how the RRC effect and the equilibrium R&D investment vary with the number of firms. In Section 3, we study a fixed-price contract, and in Section 4, we compare the resulting R&D and firm profits to those under the floating price contract of Section 2. Section 5 looks at the robustness of our results by considering more general demand functions and the case of price competition among downstream firms. Section 6 concludes.

2 Raising Rivals’ Cost Incentive for R&D: The Case of Linear Demand

Consider a two-tier industry with one upstream firm, $U$, and $n$ downstream firms indexed by $D_j$, $j = 1, \ldots, n$. The upstream firm supplies an intermediate good to the downstream firms whose output of the final product is $\{q_j\}$. Suppose the inverse demand for the final good is linear: $p = a - Q$, $Q = \sum q_j$. 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 transform-

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6 Fixed-price arrangements between upstream suppliers and downstream customers have been studied by McLaren (1999) in a different R&D context. He shows that fixed price contracts encourage autonomous innovation by the upstream supplier, but informal agreements (“handshakes”) promote joint innovation by both the supplier and the customer. In addition to this difference in focus, the RRC effect is absent in McLaren’s model because the output of each downstream producer is normalized to unity, making the demand for the input independent of downstream research investment.
ing the intermediate good into the final good being $c$. Let $w$ be the price of the intermediate good. The overall marginal cost of transforming the input into the final good for firm $D_j$ is $w + c - y_j$, 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 $\gamma y_j^2$. Throughout the paper, it is assumed that $\gamma \geq 1$ so that the R&D cost function is convex enough to ensure that the second order conditions for R&D maximization problems hold. The downstream firms make R&D decisions simultaneously, following which the input supplier sets the price of the input and the downstream firms compete in Cournot fashion in the market for the final product. We solve the equilibrium R&D investment using the standard backward induction procedure.

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

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

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

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

or equivalently,

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

Note that downstream R&D increases the demand for the input: an increase in $y_j$ shifts the derived demand outward. The upstream firm simply sets the input price at the monopoly level

$$w^* = \frac{a - c + \sum y_j/n}{2}. \quad (3)$$

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

$$Q^* = \frac{n(a - c + \sum y_j/n)}{2(n + 1)}. \quad (4)$$

Firm $D_j$’s overall marginal cost is

$$w^* + c - y_j = \frac{a + c + \sum y_k/n - 2y_j}{2},$$
implying that
\[ \frac{\partial (w^* + c - y_j)}{\partial y_j} = -\frac{2n - 1}{2n} \quad \text{and} \quad \frac{\partial (w^* + c - y_j)}{\partial y_k} = \frac{1}{2n} \quad \text{for} \quad k \neq j, \]
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 (3) into equation (1), we get the downstream Cournot quantities
\[ q_j^* = \frac{1}{2(n+1)} \left[ (a - c) + 2 \left( (n+1)y_j - \sum y_k \right) - \sum y_k/n \right] \]
and profits
\[ \pi^{D_j} = [a - \sum q_k^* - (w^* + c - y_j)]q_j^* = (q_j^*)^2. \]

At the R&D stage, each downstream firm chooses \( y_j \) to maximize \( \pi^{D_j} - \gamma y_j^2 \). Solving the first order condition and imposing the symmetry condition \( y_j = y^* \), we obtain the equilibrium R&D level for each downstream firm\(^7\)
\[ y^*(n) = \frac{a - c}{\gamma G(n) - 1}, \quad G(n) \equiv \frac{4(n+1)^2n}{2n^2 - 1}. \]

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

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

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

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

Proposition 1 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. Since the benefit of cost-reducing R&D pertains to the output a firm produces, a lower output tends to discourage 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. 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 each 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

$$
\pi_{Dj} - \gamma(y^*)^2 = \frac{(a - c + y^*)^2}{4(n+1)^2} - \gamma(y^*)^2 = \frac{(\gamma Gy^*)^2}{4(n+1)^2} - \gamma(y^*)^2 = \left[\frac{\gamma^2G^2}{4(n+1)^2} - \gamma\right](y^*)^2.
$$

Noting (4), the profit of the upstream supplier is,

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

8 See d’Aspr´emont and Jacquemin (1988), and Suzumura (1992) for example.
3 Fixed-Price Contracts

The upward adjustment of the input price by the upstream firm, though optimal ex post, tends to hamper downstream R&D as it erodes the benefit of innovation to downstream firms. Although such an adjustment also creates a strategic incentive to downstream firms to innovate so as to raise rivals’ costs as shown in Section 2, the net effect could be that downstream R&D is discouraged. Reduced downstream innovation in turn leads to reduced purchase of the input, hurting the input supplier. Therefore, it may be in the interest of all parties to find ways ex ante to alleviate or eliminate the ‘opportunistic behavior’ on the part of the supplier. Suppose the firms agree to a contract where 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 where the upstream firm commits to a prespecified input price even if the demand conditions for the input change in the future. Of course, such a fixed price contract eliminates the RRC effect which is conducive to downstream R&D.

Let the price level for the input under the fixed-price contract be \( w \). Given \( w \), the downstream firms simultaneously choose their R&D investment levels, \( y_j \). Then Cournot competition downstream yields the following quantity for firm \( D_j \) (the same as equation (1)):

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

The profit of \( D_j \) is then

\[
\pi^{D_j} = (p - w - c + y_j)q_j = (q_j)^2.
\]

At the R&D stage, firm \( D_j \) maximizes \( \pi^{D_j} - \gamma y_j^2 \), taking \( w \) as given. From the first order condition, firm \( D_j \)’s best response is

\[
y_j = \frac{a - c - w - \sum_{k \neq j}(y_k - y_j)}{\gamma(n + 1)^2/n - 1}.
\]

and the symmetric equilibrium R&D level is

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

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

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

\[ = \frac{\gamma(n + 1)(a - c - w)}{\gamma(n + 1)^2/n - 1}. \]

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

\[ w^f = (a - c)/2. \]  \hspace{1cm} (9)

Substituting this into equation (8), 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 checked that \( y^f(n) > y^*(n) \) because \( 2n/(2n^2 - 1) > 1/n \).

**Proposition 2.** A fixed-price contract by the upstream supplier promotes downstream R&D, i.e., \( y^f(n) > y^*(n) \) for all \( n \) and \( \gamma \geq 1 \).

Under a fixed-price contract, the upstream supplier commits not to raise the input price after the downstream firms have conducted R&D. This encourages R&D by eliminating the negative effect of an upward adjustment of input price on R&D. Although the RRC effect (which is conducive to downstream R&D) is also eliminated, the net effect is to promote downstream R&D. Moreover, as elaborated in Section 4 below, firm \( U \) is a Stackelberg follower in the floating price game where it chooses \( w \) after downstream R&D decisions are made, whereas under the fixed-price contract, it is a price leader and hence can influence the R&D levels of the downstream firms who are now Stackelberg followers. Since downstream R&D benefits the input supplier, it is in \( U \)'s interest to encourage such activity. The fixed price game enables firm \( U \) to induce a larger amount of R&D from the downstream firms by choosing a lower input price.

Each downstream firm’s net profit under the fixed price contract is

\[ \pi_{Dj} - \gamma (y^f)^2 = \left[ \left( \frac{n + 1}{n} \right)^2 - \gamma \right] \cdot \left[ \frac{1}{2} \cdot \frac{a - c}{\gamma(n + 1)^2/n - 1} \right]^2. \]  \hspace{1cm} (10)
while the profit of the upstream firm is

\[ \pi_U = w^f \cdot Q(w^f) = \left[ \frac{(a - c)^2}{4} \right] \left[ \frac{\gamma(n + 1)}{\gamma(n + 1)^2/n - 1} \right]. \quad (11) \]

4 Comparing the Floating and Fixed Price Contracts

We now pose the natural question: can the R&D-stimulating fixed price contract be beneficial to all firms including the upstream firm, relative to the floating price case analyzed in Section 2? As noted earlier, in the fixed price contract, the upstream supplier is a Stackelberg price leader and hence its pricing decision influences the R&D levels of the downstream firms who are Stackelberg followers. After the U firm chooses \( w \), all the downstream firms choose the symmetric R&D equilibrium given by equation (7) but with \( y_k = y_j \) for all \( k \). Thus \( y(w) \) given by equation (8) is \( D_j \)'s best response, labelled \( BR_{D_j} \) in Figure 1. It is downward sloping because a higher input price discourages downstream R&D, i.e., the input price and downstream R&D are strategic substitutes from \( D_j \)'s perspective. The fixed price equilibrium, \( (w^f, y^f) \), is given by the upstream firm’s highest isoprofit curve labelled \( \pi_U \) that is tangent to \( D_j \)'s best response.

(Insert Figure 1 here)

In the floating price scenario on the other hand, the downstream firms are Stackelberg leaders in selecting their R&D efforts while the upstream firm is a follower in setting its input price. Firm U’s best response, namely equation (3), can be rewritten as

\[ w(y_j) = \frac{a - c + y_j + \sum_{k \neq j} (y_k - y_j)/n}{2}. \quad (12) \]

Two best responses of firm U are depicted in Figure 1, both based on the above equation: \( BR_{U}^* \) represents U’s best response to \( y_j \) when \( y_k = y^* \) for \( k \neq j \), while \( BR_{U}^R \) represents U’s best response to \( y_j \) (in a reference game to be analyzed below) when \( y_k = y_j \) for all \( k \). Both best response functions are upward sloping. From U’s point of view, its input price and \( D_j \)'s choice of R&D effort are strategic complements: an increase in downstream R&D raises the demand for the input, enabling firm U to raise its input price \( w \). In the floating price game, all the other downstream firms choose the Nash equilibrium R&D level \( y^* \). Then the equilibrium in this game, \( (w^*, y^*) \), occurs where \( D_j \)'s highest isoprofit curve labelled \( \pi_{D_j} \) is tangent to U’s best response, \( BR_{U}^* \).

9 We are grateful to a referee for suggesting the following analysis.
To compare these two scenarios graphically, consider the reference game where the upstream monopolist and downstream firms simultaneously choose the input price and research levels. In this reference game, all $D_j$s choose the same R&D level (by symmetry) so the equilibrium is given by point $R$ in Figure 1 where $BR_{D_j}$ intersects $BR_i^U$. We can now easily deduce that firm $U$ is unambiguously better off under the fixed price contract than under the floating price scheme as follows. First, it is clear from Figure 1 that $(w^f, y^f)$ yields a higher profit for $U$ than at the equilibrium for the reference game, $R$, because firm $U$ can certainly do better as a price-setting leader than in the simultaneous-move reference game. To see that $R$ yields a higher profit for firm $U$ than $(w^*, y^*)$, note that the floating price scheme must result in a lower level of downstream R&D than does the reference game. This is so because when the input price and R&D levels are chosen simultaneously in the reference game, the $U$ firm takes the R&D investments of the downstream firms as given. Under the floating price scheme, however, the $U$ firm is able to adjust the input price after the downstream firms’ R&D decisions are made, thereby discouraging R&D. Therefore, the equilibrium point of the reference game, $R$, yields a higher profit for $U$ than at the equilibrium of the floating price game, $(w^*, y^*)$.

However, Figure 1 does not directly reveal that firm $D_j$ is better off at the fixed price contract. Although the point $(w^f, y^f)$ lies above the isoprofit curve $\pi_{D_j}$ of firm $D_j$ passing through the floating price equilibrium $(w^*, y^*)$, the profit level associated with $\pi_{D_j}$ is predicated on all downstream firms choosing the R&D effort level of $y^*$. The profit level at the fixed price contract, however, requires everyone to choose the larger $y^f$ which implies greater research costs but also greater profits gross of research costs. While it is difficult to rank $D_j$’s profits from this analysis, numerical simulations show that they are indeed better off under a fixed price contract for the case of linear demand considered here. Even if the downstream firms were worse off under the fixed contract, the upstream monopoly has an incentive to switch to such a contract because doing so always increases its profit.

**Proposition 3.** Assuming that the demand for the final product is linear and the R&D cost function is $\gamma y^2$, a fixed price contract by the upstream firm makes all firms better off for all $n \geq 2$ and $\gamma \geq 1$.

Since industry output increases with the R&D level, consumers benefit with the increased innovation, and therefore in the linear demand case analyzed

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10 In fact, it is straightforward to show that the equilibrium R&D level in the reference game is $y^R = \frac{a - c}{2(n+1)[2/n] - 2}$ which is smaller than $y^*$ for all $n \geq 2$ and $\gamma \geq 1$.

11 It can be shown that the isoprofit $\pi_{D_j}$ is still upward sloping when it cuts through the line $BR_{D_j}$. This is because $D_j$’s best response to $w$ when $y_k = y^*$ for $k \neq j$ lies above $BR_{D_j}$.
above, the fixed-price contract improves social welfare as well.

5 Robustness of the Results

5.1 General demand

In this subsection we show that the RRC effect can arise under general demand conditions. Consider the same two-tier industry with one upstream firm and \( n \) downstream firms. The cost of production for the upstream firm is still normalized to zero; the marginal cost of transforming the intermediate good by firm \( D_j \) into the final good is now \( c_j \), so its marginal cost of producing the final good is \( w + c_j \). Suppose that the inverse demand for the final good is given by \( p = p(Q) \) where \( p' < 0, Q = \sum_{j=1}^{n} q_j \).

As in Section 2, given the input price \( w \) set by the upstream supplier, firm \( D_j \) maximizes

\[
p(Q^*) + p'(Q^*)q_j^* = w + c_j, \quad j = 1, \ldots, n
\]

(13)

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 (13) determines the Cournot equilibrium output levels in the downstream market. Summing up these first order conditions over all \( j \) we get

\[
np(Q^*) + p'(Q^*)Q^* = nw + \sum_{j=1}^{n} c_j
\]

(14)

which implicitly defines the derived demand for the input \( Q^* = Q^*(w, c_1, \ldots, c_n) \). Differentiating (14) with respect to \( c_j \) and \( w \) yields

\[
\frac{\partial Q^*}{\partial c_j} = \frac{1}{\Delta} < 0 \quad \text{and} \quad \frac{\partial Q^*}{\partial w} = \frac{n}{\Delta} < 0,
\]

(15)

where \( \Delta = (n + 1)p' + p''(\cdot)Q^* < 0 \) follows from summing across the second order conditions for all \( n \) downstream firms. Since \( \partial Q^*/\partial c_j < 0 \), 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

\[
Q^* + w \frac{\partial Q^*}{\partial w} = 0.
\]

(16)
Equation (16) implicitly defines the equilibrium input price \( w^* = w^*(c_1, \ldots, c_n) \). To see the impact of downstream R&D on the equilibrium input price, we differentiate (16) with respect to \( c_j \) and rearrange terms, yielding

\[
\frac{\partial w^*}{\partial c_j} = \frac{\frac{\partial Q^*}{\partial c_j} + w^* \frac{\partial^2 Q^*}{\partial w \partial c_j}}{-2 \frac{\partial Q^*}{\partial w} + w^* \frac{\partial^2 Q^*}{\partial w^2}}.
\tag{17}
\]

The denominator is positive by the second order condition of \( U' \)'s maximization problem. Since \( \frac{\partial Q^*}{\partial c_j} < 0 \) from (15), 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 (15), we get

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

which is non-positive if \( (n + 2)p''(\cdot) + p''''(\cdot) Q \leq 0 \) at \( Q^* \). 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 \( p'' = p''' = 0 \).

**Proposition 4.** For a 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 \( Q^*(w^*, c_1, c_2, \ldots, c_n) \).

Thus the RRC effect extends to general demand specifications as long as

\[(n + 2) \cdot p'' + Q \cdot p'''' \leq 0.\]

This also implies that the reaction function \( BR_U^R \) of the upstream supplier in the reference game is upward sloping for general demand, as depicted in Figure 1.

The downward sloping nature of the downstream firms’ reaction function in the reference game is not unique to the linear demand specification either. For a higher input price \( w \), the Cournot output for downstream firms will be lower. Since the benefit of cost-reducing R&D is positively related to a firm’s output, a lower output weakens the incentive for R&D. Consequently, the input price and downstream R&D continue to be strategic substitutes. This implies that the ranking of the equilibrium R&D levels (i.e., \( y^* < y^R < y^f \)) as revealed by Figure 1 will continue to hold for general demand. Thus our second finding that fixed price contracts promote downstream R&D is not specific to linear demand either.

\[\text{12}\] The assumption that \( p'' \leq 0 \) is standard in the literature to guarantee the concavity of Cournot profit functions.
5.2 Price competition

The aim of this subsection is to see whether our results will hold under Bertrand price competition rather than just Cournot quantity competition. Consider the case of two downstream firms\textsuperscript{13} selling differentiated products who compete in prices. Following Dixit (1979), the inverse demands for their products are given by

\[ p_1 = a - q_1 - sq_2 \quad \text{and} \quad p_2 = a - q_2 - sq_1, \]

where \( q_j \) is the output of firm \( D_j \) and \( p_j \) its price.\textsuperscript{14} Parameter \( s \in [0,1] \) represents the degree of substitutability between the two goods: the two goods are homogeneous if \( s = 1 \) and completely unrelated if \( s = 0 \). The firms buy the same input from the upstream supplier. Product differentiation arises during downstream production. As in the previous sections, each downstream firm has the same per-unit production cost of \( c \) and can conduct R&D \( y_j \) so as to reduce its marginal cost to \( c - y_j \).

5.2.1 Floating input price scenario

The downstream firms choose R&D first followed by the \( U \) firm setting \( w \). Firm \( D_j \)'s overall marginal cost is then \( c_j = w + c - y_j \). Finally they compete in the product market by setting prices. To solve for this scenario, the inverse demand system above can be inverted to give the demand equations as

\[ q_1 = \frac{a}{1+s} - \frac{p_1}{1-s^2} + \frac{sp_2}{1-s^2} \quad \text{and} \quad q_2 = \frac{a}{1+s} - \frac{p_2}{1-s^2} + \frac{sp_1}{1-s^2}. \]

Therefore

\[ Q = q_1 + q_2 = \frac{2a - (p_1 + p_2)}{1+s}. \]

\textsuperscript{13}Analytical derivations are virtually impossible for the case of an arbitrary number of downstream firms because of algebraic complexity.

\textsuperscript{14}These demand equations can be generated by maximizing the utility function

\[ U(q_1, q_2, m) = a(q_1 + q_2) - \frac{1}{2}(q_1^2 + q_2^2 + sq_1q_2) + m, \]

where \( m \) is the consumption of a numéraire good.
For given \((c_1, c_2)\), it can be derived that the equilibrium prices are
\[
p_j = \frac{a(2 + s)(1 - s) + 2c_j + sc_i}{4 - s^2}, \quad j = 1, 2, \ j \neq i. \tag{19}
\]
Substituting this into (18), we get the derived demand for the input:

\[
Q(w; y_1, y_2) = \frac{2a - c_1 - c_2}{(1 + s)(2 - s)} + \frac{2(a - c - w) + y_1 + y_2}{(1 + s)(2 - s)}.
\]

The upstream firm then chooses \(w\) to maximize \(w \cdot Q(w; y_1, y_2)\), yielding
\[
w_B^* = \frac{2a - 2c + y_1 + y_2}{4}.
\]

At the R&D stage, firm \(D_j\) chooses \(y_j\) to maximizes \((p_j - w_B^* - c + y_j)q_j - \gamma y_j^2\). Then the symmetric equilibrium level of R&D is
\[
y_B^* = \frac{a - c}{\gamma H(s) - 1}, \quad H(s) = \frac{8(1 + s)(2 + s)(2 - s)^2}{6 + s - 3s^2}.
\]

If there is only one firm in the downstream market, the R&D level is given by the solution in the case of successive monopoly considered in Section 3, namely \(y^*(1) = (a - c)/(16\gamma - 1)\). Simulations show that \(y_B^* > y^*(1)\) for all \(\gamma \geq 1\) and all \(s\): the RRC effect under price competition is strong enough so that downstream duopolists each invest more in R&D as compared to a downstream monopolist. We next consider the case of fixed price contract with a downstream duopoly.

### 5.2.2 Fixed input price scenario

Suppose that the \(U\) firm can commit to a fixed input price contract prior to R&D by the downstream firms. Given \(w\) and \((y_1, y_2)\), the equilibrium prices downstream are the same as in (19). Firm \(D_j\) chooses \(y_j\) to maximizes \((p_j - w - c + y_j)q_j - \gamma y_j^2\), yielding the symmetric equilibrium R&D level for any given \(w\) as
\[
y_B^f(w) = \frac{a - c - w}{\gamma H(s) - 1}.
\]

The \(U\) firm maximizes \(w \cdot Q(w; y_B^f, y_B^f)\) which yields \(w^f = (a - c)/2\). Hence
\[
y_B^f(w^f) = \frac{a - c}{\gamma L(s) - 2}, \quad L(s) = \frac{(1 + s)(2 + s)(2 - s)^2}{2(2 - s^2)}.
\]
It is easily seen that $L(s) < H(s)$ (because $6 + s + 13s^2 < 32$ for all $s$). Thus, $y_B^f(w^f) > y^*_B$ for all $s$ and a fixed price contract promotes downstream R&D even when firms compete in prices. This result we believe generalizes to the case of several downstream firms for reasons analogous to those presented in the case of quantity competition.

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.

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 large. 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 fix input prices. One possibility is 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 illegal per se under antitrust laws) may potentially be welfare-improving by encouraging downstream innovation.
One can also extend our analysis by allowing 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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References

\( y_f = \frac{a - c}{2} \)

\( y^* \)

\( w^* \)

\( R \)

\( \pi^D_j \)

\( \pi^U \)

\( BR^*_U \): U’s best response to \( y_j \) when all \( y_k = y_j \)

\( BR^R_U \): U’s best response to \( y_j \) when \( y_k = y^*, k \neq j \)

\( BR^R_{Dj} \): \( D_j \)'s best response to \( w \) when all \( y_k = y_j \)

\textbf{Figure 1}