

Vertical integration and R&D information flow: is there a need for ‘firewalls’?

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Abstract

We examine the impact of R&D information flow on innovation incentives and welfare. In particular, we consider the case in which the information flows from a downstream nonintegrated firm to the downstream division of a vertically integrated firm via its upstream subsidiary. In a setting where both the integrated and nonintegrated firm engage in cost-reducing R&D and compete in the product market, we show that the impact of the R&D information flow on innovation, output, and profits is positive for the integrated firm, and negative for the nonintegrated firm. Unless information spillovers are high, goods are close substitutes, and R&D is very costly, ‘firewalls’ decrease welfare.

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1. Introduction

There has been a recent resurgence of interest in the potential anticompetitive effects of vertical mergers. The Antitrust Division of the Department of Justice (DOJ) and the Federal Trade Commission (FTC) of the United States have intervened in a series of vertical merger cases and issued consent decrees placing various behavioral restrictions on

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the postacquisition firms. These behavioral restrictions are motivated by the Antitrust Authorities' concern that the nonpublic information obtained by a vertically integrated firm could be used anticompetitively.¹

Consider a market structure in which an upstream firm is supplying an intermediate good to a number of downstream firms and at the same time is vertically integrated with one of these downstream firms. In this setting, the Antitrust Authorities are concerned that the information derived by the upstream supplier through its vertical relations with its downstream customers will be shared with its downstream integrated subsidiary, leading to a reduction in innovation incentives and downstream competition.

These concerns become relevant when important information, particularly information about the technology, the design or the specific characteristics of the products must be shared between the upstream and the downstream firms. This is typical in R&D intensive industries, where the exchange of information about the upstream and downstream products, is necessary in order for the products to be compatible, to avoid extra costs of adjustment, and to increase functionality.

In practice, concerns regarding the effects of the information flow were raised in a series of vertical merger cases which took place in a number of different R&D intensive industry sectors: defense (Raytheon/Chrysler, Boeing/Rockwell, Alliant/Hercules, Lockheed/Loral), pharmaceuticals (Merc/Medco), telecommunications (AT&T/McCaw, MCI/BT), satellites (Boeing/General Motors, Martin Marietta/General Dynamics), and energy (PacifiCorp/Energy Group).² In all these merger cases, the upstream and downstream firms were working closely together, and the upstream division of the vertically integrated firm was receiving nonpublic information about the products of its downstream customers in its capacity as an upstream input supplier. Hence, the upstream division of the vertically integrated firm could transfer this nonpublic information to its own downstream subsidiary. In all these cases, the DOJ and the FTC assumed that such information transfer, among other things, would reduce competition and firms' innovation incentives. Thus, although they allowed the vertical mergers to take place, they required the establishment of a 'firewall' between the merging parties.

A 'firewall' is a behavioral requirement that prohibits the different divisions of a vertically integrated firm from communicating about nonpublic information received by one of the divisions from outside parties. In the implementation of a 'firewall', the upstream division of the integrated firm is asked to use the downstream competitor's proprietary information only in its capacity as its supplier, and not to provide it, disclose it or otherwise make it available to its downstream subsidiary. It is also asked to inform its nonintegrated downstream customers about this nondisclosure requirement before obtaining any information from them that is outside the public domain. Finally, the integrated firm is required to permit the authorized representatives of the Antitrust

¹ Nonpublic information in this context includes any information not available in the public domain. For example, information about design and technological specifications, private costs, bids, marketing strategies.

² FTC Docket N.C-3681, 9/1996; FTC File N.9710006, 12/1996; FTC File N.9410123, 11/1994; FTC Docket N.C-3685, 9/1996; Civil Action N.94-01555; Civil Action N.94-1317; FTC File N.9510097, 8/1998; File N.0010092, 9/2000; Martin Marietta Decree in 59 Federal Regulation; FTC File N.9710091, 2/1998.

Authorities to have access to all its books, documents, correspondence, reports, memoranda, and accounts and to interview officers and employees in order to determine compliance with the ‘firewall’ requirement.

It is questionable whether or not the implementation of ‘firewalls’ can be successful. However, a more essential and unanswered question is if there is a need for ‘firewalls’ or not, in other words if the information flow does actually reduce innovation incentives and social welfare.

To answer this question, we use a simple model in which a vertically integrated firm has the monopoly in the upstream market and at the same time competes in the downstream market with a nonintegrated downstream firm. A three-stage game is analyzed. In the first stage, both the integrated and the nonintegrated firm choose their level of cost-reducing R&D. In the second stage, the integrated firm chooses the wholesale price of the input. Finally, in the third stage, the two firms produce differentiated goods and compete in the final goods market in quantities. The R&D paths of the two firms are assumed to be complementary as in [d’Aspremont and Jacquemin \(1988\)](#), but in an extension of the basic model we also consider the case in which the firms’ R&D paths are substitutes.³

Our main finding is that the information flow does not necessarily reduce R&D incentives and welfare. In particular, we show that the information flow leads to lower innovation incentives for the nonintegrated firm, but to higher incentives for the integrated firm, at least when firms’ R&D paths are complementary. In contrast, when firms are involved in an R&D race, the R&D incentives of the integrated firm decrease with information flow. However, under both R&D specifications, the effective R&D of the integrated firm is higher under information flow than under a ‘firewall’. Under complementary R&D paths, welfare is higher under information flow than under a ‘firewall’, unless spillovers are very high, goods are very close substitutes, and R&D is too costly. Moreover, under substitute R&D paths, welfare seems to be higher under information flow. Thus, our analysis provides insights against the policy intervention and the implementation of ‘firewalls’.

There is little economic research regarding the competitive effects of ‘firewalls’ following vertical integration. [Thomas \(1996\)](#) considers a market in which a vertically integrated firm co-exists with a nonintegrated upstream and downstream firm, and examines the impact of information flow regarding the opponent’s bids on firms’ profits. He finds that although both divisions of the integrated firm are indifferent about the information flow, the nonintegrated downstream firm prefers a ‘firewall’, while the nonintegrated upstream firm prefers information flow.

In a more recent paper, [Hughes and Kao \(2001\)](#) assess the impact of ‘firewalls’ on welfare, showing that they decrease both consumer surplus and overall welfare. However, they find that ‘firewalls’ increase the integrated firm’s profits, which means that the

³ When firms’ research paths are substitutes, firms follow exactly the same research line and thus they essentially make the same discovery. When firms’ research paths are complements, firms follow different research lines leading them to different discoveries (see [Katsoulacos and Ulph, 1998](#)).

upstream division of the integrated firm has no incentives to reveal information to its downstream subsidiary in the first place. Hence, in their framework, there is no reason for information transmission concerns to be raised.

In both of these papers there is competition in the upstream market, which affects the firms' market decisions and hence their conclusions. The present paper instead concentrates on the case of an upstream monopoly in order to focus on the consequences of the information flow and to be closer to the market structures in which the Antitrust Authorities concerns were raised. Notice also that Thomas' paper refers to information about the opponent's bids and Hughes and Kao's to information about the rival's private demand. Neither paper considers R&D investments and the flow of R&D information, hence they do not capture the latter's effect on innovation incentives and welfare.

The rest of the paper has the following structure. In Section 2, the basic model is described in detail. In Section 3, the equilibrium analysis is presented. In Section 4, 'firewalls' are compared with information flow. In Section 5, our welfare findings are provided. In Section 6, the analysis is extended to the case of an R&D race model with substitute research paths. Finally, in Section 7, our main results are summarized and possible policy implications as well as extensions of our model are discussed. All the proofs of the Propositions are included in the Appendix.

2. The basic model

We consider an industry consisting of two firms, a vertically integrated firm, denoted by $U-D_1$, and an independent downstream firm, denoted by D_2 (see Fig. 1). The upstream division of the integrated firm, U , is a monopolist, and produces an input, which is essential for the production of the final goods.

For simplicity, we assume that the input monopolist, or 'bottleneck owner' U , has no fixed costs, no capacity constraints, and faces a constant marginal cost, which without loss of generality we set equal to zero.⁴ The downstream division of the integrated firm D_1 obtains the input from U at marginal cost, while the nonintegrated downstream firm D_2 obtains it at an endogenously determined wholesale price w . The two downstream firms transform the input into the final good on a one-to-one basis.

We analyze a full information three-stage game. In the first stage, firms simultaneously and independently choose their R&D effort levels. In the second stage, $U-D_1$ makes a "take-it-or-leave-it" offer to D_2 regarding the wholesale price w of the input. Finally, in the third stage, firms produce differentiated goods and compete in quantities.⁵ We assume subgame perfection throughout the paper.

⁴ "A 'bottleneck' firm's product cannot be cheaply duplicated by users who are denied access to it" (Rey and Tirole, *forthcoming*). We assume that the possibility of bypassing the 'bottleneck' is so costly that it does not exist.

⁵ In an appendix, which is available upon request, we analyze the case of price competition and find that all the qualitative results of the basic model are confirmed.

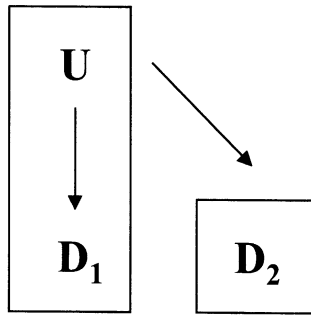


Fig. 1. Partially vertically integrated industry.

Inverse demand and cost functions

The inverse demand functions for firms U-D₁ and D₂ are, respectively:

$$p_1 = a - q_1 - dq_2; \quad p_2 = a - q_2 - dq_1; \quad a > 0, \quad 0 \leq d < 1 \quad (1)$$

where q_1 and q_2 are the final good quantities of firms U-D₁ and D₂ and d is the degree of product differentiation.⁶

Following d'Aspremont and Jacquemin (1988), we assume that the cost functions for firms U-D₁ and D₂ are:⁷

$$C_1(x_1, x_2, k, q_1) = (A - x_1 - kx_2)q_1; \quad C_2(x_2, w, q_2) = (A + w - x_2)q_2 \quad (2)$$

$$x_1 \geq 0, \quad x_2 \geq 0, \quad A \geq x_1 + kx_2, \quad A \geq x_2 - w, \quad 0 \leq k \leq 1$$

where x_1 and x_2 are the R&D investments of firm U-D₁ and D₂, respectively. If no R&D investments are undertaken, the unit cost of both firms is given by A . The parameter k represents the degree of R&D spillovers. It reflects the extent to which a downstream firm absorbs technological knowledge from the R&D investments of its competitor, as well as the productivity of the acquired knowledge in decreasing the production cost of its final product.

In order to incorporate the effect of the information flow between the two divisions of the integrated firm, it is assumed that the nonintegrated downstream firm does not enjoy any spillovers ($k=0$), while the integrated firm enjoys spillovers ($k>0$) only when there is flow of information about the R&D undertaken by D₂, between the different divisions of U-D₁. In other words, we set $k=0$ in Eq. (2) when there is a 'firewall', while in the absence of a 'firewall', $k>0$. Note that even in the absence of R&D investments, the

⁶ The demand functions are derived from the representative consumer's utility, which depends on the quantities of the final products and the numeraire good m and takes the following form (see Singh and Vives, 1984): $U = a(q_1 + q_2) - (1/2)(q_1^2 + q_2^2 + 2dq_1q_2) + m$.

⁷ In Section 6, we extend the analysis to the case of substitute research paths.

nonintegrated firm D_2 faces an extra cost w , the wholesale price that it has to pay in order to obtain the input from the upstream supplier U.

The R&D investments are subject to diminishing returns, as captured by the quadratic form of the cost of R&D:

$$\Gamma(x_i) = \mu \frac{x_i^2}{2}, \quad \mu > 0, \quad i = 1, 2 \quad (3)$$

Eq. (3) implies that the cost per unit of R&D increases with the size of the research lab. That is, higher R&D levels require proportionally higher costs of lab operation. Moreover, a higher cost parameter μ reflects a lower efficiency of the R&D expenditures.

In order to guarantee that the second order conditions are satisfied and that the firms choose strictly positive quantities and R&D levels, we assume the following throughout the paper:

Assumption 1. The degree of product differentiation d is lower than \bar{d} , where $\bar{d} = 1 - (1/2\mu)$.⁸

3. Equilibrium analysis

The profit functions of U- D_1 and D_2 are:

$$\pi_{v1} = wq_2 + (a - q_1 - dq_2)q_1 - (A - x_1 - kx_2)q_1 - \mu \frac{x_1^2}{2} \quad (4)$$

and

$$\pi_2 = (a - q_2 - dq_1)q_2 - (A + w - x_2)q_2 - \mu \frac{x_2^2}{2}, \quad (5)$$

respectively. Note that the profits of the integrated firm include both its revenue from the input sales and from the final good sales.

In the last stage of the game, each firm chooses its output in order to maximize its profits. The first order conditions give rise to the following quantity reaction functions:

$$R_1(q_2) = \frac{v + (x_1 + kx_2) - dq_2}{2}; \quad R_2(q_1) = \frac{v + (x_2 - w) - dq_1}{2} \quad (6)$$

where $v = a - A > 0$ denotes the market size. Observe that the terms within the parentheses represent the ‘effective’ unit cost reduction of each firm. Solving for the Cournot–Nash equilibrium quantities of the final goods, we obtain:

$$q_1^C(w, x_1, x_2) = \frac{v(2 - d) - d(x_2 - w) + 2(x_1 + kx_2)}{4 - d^2} \quad (7)$$

⁸ As can be seen from Eq. (18) below, when d is too high ($d > \bar{d}$), market foreclosure arises.

$$q_2^C(w, x_2, x_1) = \frac{v(2-d) + 2(x_2 - w) - d(x_1 + kx_2)}{4 - d^2} \quad (8)$$

In the second stage of the game, U-D₁ chooses the wholesale price in order to maximize its profits. Substituting (7) and (8) into (4) and taking the first order condition with respect to w , we obtain:

$$w(x_1, x_2, k) = \frac{v(8 - 4d^2 + d^3) + d^3x_1 + x_2(kd^3 + 4(2 - d^2))}{2(8 - 3d^2)} \quad (9)$$

An inspection of (9) reveals that the wholesale price of the input is always positive; hence, D₂ always faces a cost disadvantage relative to U-D₁.

Substituting (9) into (7) and (8), we obtain the firms' output as a function of their R&D investments:

$$q_1(x_1, x_2, k) = \frac{v(8 - 2d - d^2) + x_1(8 - d^2) - x_2(2d - k(8 - d^2))}{2(8 - 3d^2)} \quad (10)$$

$$q_2(x_1, x_2, k) = 2 \frac{v(1 - d) - dx_1 + x_2(1 - dk)}{(8 - 3d^2)} \quad (11)$$

In the first stage of the game, firms choose their R&D levels in order to maximize their profits. Substituting the wholesale price and quantities given by Eqs. (9)–(11) in the profits functions (4) and (5), and differentiating the profits of U-D₁ with respect to x_1 and of D₂ with respect to x_2 , we obtain the firms' R&D reaction functions:

$$R_1(x_2, k) = \frac{v(8 - 4d + d^2) - x_2(4d - k(8 + d^2))}{2\mu(8 - 3d^2) - (8 + d^2)} \quad (12)$$

$$R_2(x_1, k) = \frac{8(1 - dk)(v(1 - d) - dx_1)}{\mu(8 - 3d^2)^2 + 8dk(2 - dk) - 8} \quad (13)$$

Given that the denominators of both reaction functions are positive, it is clear from (13) that the reaction function R_2 has a negative slope, i.e. R&D efforts are strategic substitutes from D₂'s point of view. That is, an increase in U-D₁'s effort reduces the incentives of D₂ to invest in R&D, both in the case of a 'firewall' ($k=0$) and in the case of information flow ($k>0$). In contrast, R&D efforts can be either strategic substitutes or complements from U-D₁'s point of view. This is reflected in (12) where the slope of the reaction function depends on the sign of the term in the numerator that multiplies x_2 . As

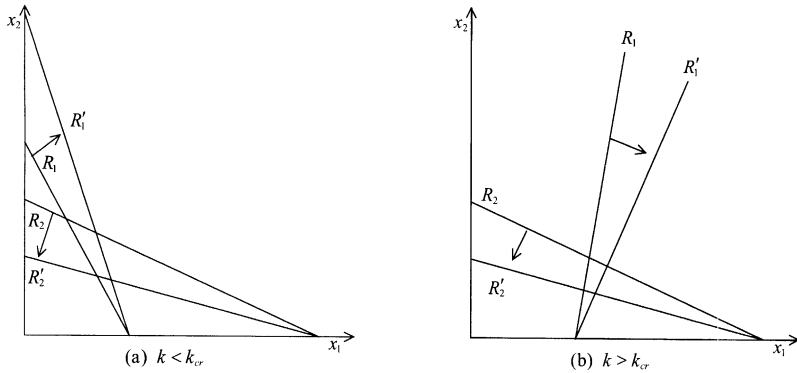


Fig. 2. R&D reaction functions.

in d’Aspremont and Jacquemin (1988), R&D investments are strategic substitutes (complements) only for low (high) degree of spillovers, in particular when k is smaller (greater) than

$$k_{cr} = 4d / (8 + d^2).^9$$

Fig. 2(a) depicts the case in which R&D investments are strategic substitutes for both firms. In this case, when the nonintegrated firm decreases its R&D investments, the integrated firm increases its own investments. However, in the case that the R&D investments are strategic complements only from the integrated firm’s point of view—see Fig. 2(b)—the integrated firm reacts to a decrease in the R&D investments of the nonintegrated firm by decreasing its own R&D expenses. The arrows indicate how the reaction curves move as k increases (see the next section for an extensive analysis of the R&D reaction functions).

From Eqs. (12) and (13), it follows that the equilibrium R&D effort levels are:

$$x_1^*(k) = v \frac{B + K}{D + L} \tag{14}$$

$$x_2^*(k) = 8v \frac{(1 - dk)E}{D + L} \tag{15}$$

where

$$B = \mu(16(4 - 2d - d^2) + 3d^3(4 - d)) - 8 > 0; \quad K = 8k(1 + d(1 - k)) > 0$$

⁹ See De Bondt et al. (1992) for a similar relation between the critical value of k and d with two-way spillovers.

$$D = \mu(2\mu(8 - 3d^2)^2 - 16(5 - d^2) + 3d^4) + 8 > 0$$

$$L = 8dk(2\mu(2 - dk) - 1) > 0; \quad E = 2\mu(1 - d) - 1 > 0$$

Finally, substituting the equilibrium R&D effort levels (14) and (15) into (9), (10) and (11), we obtain the equilibrium wholesale price and quantities:

$$w^*(k) = \mu\nu \frac{F + dK}{D + L} \quad (16)$$

$$q_1^*(k) = \mu\nu \frac{G + K}{D + L} \quad (17)$$

$$q_2^*(k) = \mu\nu \frac{2H}{D + L} \quad (18)$$

where

$$F = \mu(8(8 - 7d^2 + d^3) + 3d^4(4 - d)) - 4(8 + 2d - 3d^2) > 0$$

$$G = \mu(16(4 - d - 2d^2) + 3d^3(2 + d)) - 8(1 + d) + 3d^3 > 0$$

$$H = (8 - 3d^2)(2\mu(1 - d) - 1) > 0$$

Before turning to the comparison between information flow and ‘firewall’, it is worth mentioning that the integrated firm undertakes higher R&D investments and produces more output than the nonintegrated firm both in the case of a ‘firewall’ ($k=0$) and in the case of information flow ($k>0$). This result reflects its competitive advantage relative to the nonintegrated firm, which has to pay a higher price for obtaining the input.

Proposition 1. For all the values of k , $0 \leq k \leq 1$,

(i) the R&D investments of the integrated firm exceed the R&D investments of the nonintegrated firm: $x_1^*(k) > x_2^*(k)$,

(ii) the output of the integrated firm exceeds the output of the nonintegrated firm: $q_1^*(k) > q_2^*(k)$.

4. ‘Firewall’ versus information flow

In this part of the paper we compare the case of a ‘firewall’ with that of information flow, and we discuss the effect of information flow on innovation, wholesale price, output, and profits. We start by specifying how the R&D efforts of each firm behave with the degree of information flow, taking into account that a ‘firewall’ requirement corresponds

to the case of zero spillovers.¹⁰ Our main findings are summarized in the following Proposition:

Proposition 2.

- (i) *The R&D investments of the nonintegrated firm decrease as the degree of spillovers k increases, for $0 \leq k \leq 1$.*
- (ii) *The R&D investments of the integrated firm increase as the degree of spillovers k increases, for all $k \leq \max\{1, \hat{k}\}$, where $\hat{k} > k_{cr}$, and are always higher under information flow ($k > 0$) than under a ‘firewall’ ($k = 0$).*

In accordance with the expectations of the Antitrust Authorities, we find that the information flow has a negative impact on the nonintegrated firm’s incentives to innovate. That is, D_2 undertakes lower R&D investments when there is information flow than when there is a ‘firewall’. This is due to the lack of full appropriability of its innovations under information flow, which reduces its incentives to carry out research projects. In contrast with the expectations of the Antitrust Authorities, however, we find that $U-D_1$ undertakes higher R&D levels under information flow than under a ‘firewall’ requirement. Intuitively, the R&D spillovers reduce the costs of $U-D_1$; this leads to an increase in output which in turn reinforces the value of any cost reduction, inducing an increase in its own R&D investments. A straightforward consequence is that the ‘effective’ R&D of $U-D_1$, $x_1 + kx_2$, is also higher under information flow than under a ‘firewall’.¹¹

Proposition 2 also states that an increase in the degree of spillovers k leads to a decrease in the R&D efforts of D_2 . This can also be seen in Fig. 2(a and b) where the arrows indicate the direction in which the reaction functions move when k increases. An increase in k rotates counter-clockwise the reaction function of D_2 around its intersection with the horizontal axis in both graphs. Intuitively, an increase in the one-way spillovers from D_2 to $U-D_1$ further discourages D_2 from investing in R&D, since a larger part of its inventions is now exploited by its rival.

On the other hand, an increase in k rotates clockwise the reaction function of the integrated firm around its intersection with the x_1 axis. In particular, if k is such that the R&D investments are strategic substitutes for firm $U-D_1$ (see Fig. 2(a)), an increase in k makes the R_1 curve steeper, with negative slope. Intuitively, an increase in the degree of spillovers, given that the R&D investments are strategic substitutes, reinforces the output effect of the R&D spillovers mentioned above, thus inducing a further increase in the integrated firm’s R&D investments.

In the case that the R&D investments are strategic complements for the integrated firm, inspection of Fig. 2(b) reveals that the impact of an increase in k on the integrated firm’s R&D expenses is positive for values of k above and close enough to

¹⁰ For an analysis of the information flow’s impact on the aggregate effective R&D, see an earlier version of the paper in Milliou (2001).

¹¹ The term ‘effective’ R&D refers to a firm’s total unit cost reduction that consists of both the firm’s own R&D and its benefit from its rivals’ investments due to spillovers (see Kamien et al., 1992; De Bondt et al., 1992).

k_{cr} , while for higher values of k it may be negative. The intuition for the latter case is simple. If the R&D investments are strategic complements for the integrated firm, an increase in the degree of spillovers makes the R&D efforts stronger strategic complements for U-D₁. We know that D₂ will react to an increase in k by decreasing its R&D efforts. If the R&D investments are too costly (i.e. μ is high enough), U-D₁ also has an incentive to reduce its R&D efforts in order to save on R&D costs. The latter positive effect more than compensates the negative effect on profits due to the smaller unit cost reduction.

Next we examine the effect of the information flow on firms' output. Since the investments in R&D allow firms to reduce their unit production costs, an increase (decrease) in the effective R&D investments of a firm, should lead to an increase (decrease) in the firm's output. Note, however, that the effective unit cost reduction of D₂, and hence its output, also depends on the change in the input price charged by U-D₁. Comparing the wholesale price under a 'firewall' with that under information flow, we find not only that the former exceeds the latter, but also that the wholesale price decreases with k (see Proposition 3 below). The intuition behind this lies in the information flow's impact on the derived demand of the input. In particular, information flow discourages D₂ from conducting R&D and thus decreases its demand for the input, leading U-D₁ to charge a lower input price to avoid losing too much in profits from its input sales.¹²

Proposition 3. *The wholesale price of the input decreases as the degree of spillovers k increases, for $0 \leq k \leq 1$.*

The decrease in the wholesale price in the absence of a 'firewall', ceteris paribus, reduces the cost advantage of the integrated firm's downstream division and improves the competitive position of the nonintegrated downstream firm. However, the R&D effect dominates the wholesale price effect, and hence, information flow leads to an increase in the output of the integrated firm and a decrease in the output of the nonintegrated firm. The following Proposition summarizes:

Proposition 4.

- (i) *The output of the nonintegrated firm decreases as the degree of spillovers k increases, for $0 \leq k \leq 1$.*
- (ii) *The output of the integrated firm increases as the degree of spillovers k increases, for all $k \leq \max\{1, \bar{k}\}$, where $\bar{k} > k_{cr}$, and is always higher under information flow ($k > 0$) than under a 'firewall' ($k = 0$).*

Before turning to the welfare analysis, it is important to examine whether the integrated firm does indeed have incentives to let information flow. In other words, it is important to investigate whether or not the integrated firm has incentives to set up a 'firewall' on its

¹² For an explanation along these lines see Banerjee and Lin (2003).

own without the intervention of the Antitrust Authorities. To do so we compare its profits with and without a ‘firewall’.

Proposition 5.

(i) *The profits of the nonintegrated firm decrease as the degree of spillovers k increases, for $0 \leq k \leq 1$.*

(ii) *The profits of the integrated firm increase as the degree of spillovers k increases, for all $k \leq \max\{1, \bar{k}\}$, and are always higher under information flow ($k > 0$) than under a ‘firewall’ ($k = 0$).*

In the absence of a ‘firewall’, there are two different forces at work. On the one hand, information flow allows U-D₁ to free-ride on the investments of its competitor, enabling it to increase its effective R&D and thus to expand its downstream business and increase its profits from the final product sales. On the other hand, information flow hinders the R&D incentives of D₂, thereby reducing its demand for the input, leading to a lower wholesale price and hence to lower profits from the upstream market for the integrated firm. As Proposition 5 states, the former positive effect dominates the latter negative effect. The net effect is thus an increase in the profits of the integrated firm due to the information flow. This finding, which contrasts with the result of Hughes and Kao (2001), confirms that in the absence of government intervention the upstream firm does have incentives to transfer to its downstream subsidiary the information that it possesses about its downstream rival. Regarding the nonintegrated firm, the decrease in its profits when the spillovers increase is a straightforward consequence of the decrease in its R&D investments and output (Proposition 2 and Proposition 4).

5. Welfare analysis

In order to answer the question whether or not the Antitrust Authorities should use ‘firewalls’, we turn to a welfare analysis. In particular, we compare the total welfare under information flow with that under a ‘firewall’. We define total welfare as the sum of producers’ and consumers’ surplus:

$$W(k) = (a - A)(q_1 + q_2) - \frac{1}{2}(q_1^2 + q_2^2 + 2dq_1q_2) + (x_1 + kx_2)q_1 + x_2q_2 - \frac{\mu}{2}(x_1^2 + x_2^2) \quad (19)$$

As it turns out, the net effect of the information flow on social welfare depends on the efficiency of the R&D technology μ , the degree of product differentiation d , and the rate of spillovers k .

Proposition 6. *For small and moderate values of μ , as well as for large values of μ when d is sufficiently low, welfare is always higher under information flow ($k > 0$) than under a*

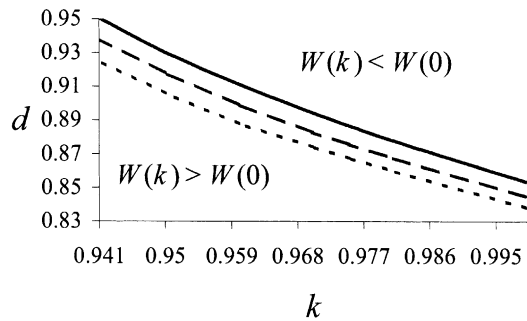


Fig. 3. Welfare comparison for $v=1$, $\mu=8$ (—), $\mu=9$ (---) and $\mu=10$ (- -).

'firewall' ($k=0$). For large values of μ and d high enough, there exists a \bar{k} such that for all $k > \bar{k}$ welfare is higher under a 'firewall' ($k=0$) than under information flow ($k > 0$), and vice versa for all $k < \bar{k}$. Moreover, \bar{k} is decreasing in μ .

In other words, for small or moderate cost of R&D, welfare under information flow always exceeds that under a 'firewall'. To gain some intuition, recall from Proposition 1 that U-D₁ enjoys a larger market share than D₂ both in the absence and in the presence of information flow since it does not face the double mark-up problem faced by D₂.¹³ In other words, the two firms are asymmetric even in the absence of the R&D investments, and obviously the integrated firm is the most efficient one since it faces a lower marginal production cost. According to Proposition 2 and Proposition 4, the presence of information flow increases the cost advantage of U-D₁ as well as its market share. Thus, under information flow output shifts to the more efficient firm, entailing an increase in social welfare. Note that the same welfare result holds for higher values of R&D cost, provided that the firms' products are sufficiently differentiated.

However, when the cost of R&D is quite high and the goods are very close substitutes, the above result could be reversed, provided that the degree of spillovers is high enough, i.e. $k > \bar{k}$. As Fig. 3 shows, welfare under a 'firewall' is higher than under information flow if e.g. $\mu=10$ and $d=0.84$ for all $k > 0.99$, while if $\mu=10$ and $d=0.949$ for all $k > 0.926$. The intuition is as follows. If R&D is very costly, even the integrated firm will only undertake minimal amounts of R&D and hence the extra cost reduction due to information flow plays a rather insignificant role in the welfare comparison. Furthermore, when k is very high, the appropriability problem of the nonintegrated firm is so severe that D₂ undertakes very low investments in R&D and in turn U-D₁ benefits less from the information flow. Note also that the appropriability problem of D₂ becomes stronger the closer substitutes the final goods are, since the fiercer the competition, the stronger the negative impact of the lack of full appropriability on D₂'s R&D investments. The combination of all these effects may lead to a reversal of

¹³ We are grateful to an anonymous referee for pointing this out.

the welfare result. For this reversal to occur, it is required that the goods are close substitutes, R&D is quite costly, and the degree of spillovers is high.

6. Extension: an R&D race model

In this section we examine the robustness of our main results under an alternative R&D specification in which the firms are involved in an R&D race for the same innovation. We model R&D as a stochastic process. Moreover, we assume that the two firms follow substitute research paths. In particular, both firms are engaged in R&D investments that, if successful, lead to the same cost-reducing innovation h , with $A - h \geq 0$ and $d < (a - A)/(a - A + h)$. A firm's R&D investments determine the probability ρ with which it will make a discovery. The cost of R&D investments is given by:

$$G(\rho_i) = \mu(-\rho_i - \log(1 - \rho_i)), \quad 0 \leq \rho_i \leq 1, \quad \mu > 0, \quad i = 1, 2 \quad (20)$$

so that

$$G(0) = G'(0) = 0, \quad G'(\rho_i) > 0, \quad G''(\rho_i) < 0, \quad \lim_{\rho_i \rightarrow 1} G(\rho_i) = \lim_{\rho_i \rightarrow 1} G'(\rho_i) = \infty$$

To capture the one-way spillovers in the case of information flow, we assume that U-D₁ innovates if it succeeds directly, or if it manages to imitate D₂'s innovation, i.e. with probability $\rho_1 + (1 - \rho_1)k\rho_2$, where k represents again the degree of spillovers, $0 \leq k \leq 1$, while D₂ innovates with probability ρ_2 .

Depending on the failure or success of the discovery, we denote the profits of the integrated and nonintegrated firms as: π_{V1}^B, π_2^B if both firms innovate, π_{V1}^N, π_2^N if neither of the firms innovates, π_{V1}^I, π_2^I if U-D₁ alone innovates, and π_{V1}^D, π_2^D if D₂ alone innovates. It follows that the expected profits of U-D₁ are given by:

$$E(\pi_{V1}) = (\rho_1 + (1 - \rho_1)k\rho_2)\rho_2\pi_{V1}^B + \rho_1(1 - \rho_2)\pi_{V1}^I + (1 - \rho_1)(1 - k\rho_2)\rho_2\pi_{V1}^D + (1 - \rho_1)(1 - \rho_2)\pi_{V1}^N - G(\rho_1) \quad (21)$$

with a similar expression holding for D₂. The timing of the game is the same as in the basic model. As previously, we find that the R&D investments, the expected output and profits of the nonintegrated firm, as well as the expected wholesale price, are lower under information flow than under a 'firewall', while the opposite holds for the expected output and profits of the integrated firm.¹⁴ The R&D race specification of the investment stage though alters the R&D incentives of the integrated firm, which no longer invests more under information flow than under a 'firewall'. This last result is due to the different nature of R&D investments used in this extension. Here, the R&D investments of the two firms,

¹⁴ Due to the multistage nature of the game, the asymmetry of the two firms and the exogenous level of cost reduction, analytical solutions are intractable in this model, and our results are based on numerical methods.

if successful, lead to the same level of cost reduction. For instance, in the case that U-D₁ succeeds on its own in achieving the cost reduction h , the spillovers from D₂ in case it succeeds as well, do not lead to a greater cost reduction, and hence they do not increase the incentives for further investments in R&D. Moreover, due to the existence of the spillovers, U-D₁ can achieve the same cost reduction by incurring fewer expenses in R&D, thus enjoying higher profits than under a ‘firewall’. What is important to notice though is that the expected effective R&D of the integrated firm, that is its expected total cost reduction $x = \rho_1 + (1 - \rho_1)k\rho_2$, is higher under information flow than under a ‘firewall’, just as in the basic model.

As regards welfare, numerical calculations indicate that when firms race for a unique cost-reducing innovation, information flow is preferable to a ‘firewall’. The main intuition behind this result does not only come from the asymmetric market shares effect mentioned above, but also from the fact that spillovers now contribute to reducing the duplication of the R&D investment costs. In the absence of spillovers there exists duplication of R&D expenses. Information flow reduces the R&D investments and thus the duplication of the expenses, without, however, necessarily decreasing the total cost reduction, and hence it leads to an increase in welfare.

7. Conclusions

We have investigated the impact of information flow on firms’ R&D incentives and welfare in a partially vertically integrated industry. We have used a simple model, in which a vertically integrated firm has the monopoly in the upstream market and competes with a nonintegrated firm in the downstream market. Both firms undertake cost-reducing R&D investments, produce differentiated goods and compete in the final goods market.

We have shown that if information regarding the R&D of the nonintegrated downstream firm flows between the different divisions of the vertically integrated firm, the nonintegrated firm’s incentives to innovate are reduced, but those of the integrated firm may be increased. The latter occurs when the firms’ research paths are complementary (as in d’Aspremont and Jacquemin, 1988). In contrast, when firms are involved in an R&D race for a unique cost-reducing innovation, the R&D incentives of the integrated firm decrease with the information flow. However, under both R&D specifications, the effective R&D of the integrated firm is higher under information flow than under a ‘firewall’. Our findings thus cast some doubt on the concerns of the Antitrust Authorities that information flow is detrimental to the firms’ innovation activities.

Our welfare results also provide insights against the implementation of ‘firewalls’ in a wide set of circumstances. In particular, we have shown that under complementary research paths welfare is higher under information flow than under a ‘firewall’, unless information spillovers are high, goods are close substitutes and R&D is quite costly. Moreover, under substitute research paths, welfare is also typically higher under information flow.

Nevertheless, before any policy conclusions be taken too literally, one has to recall that our results are based upon a number of simplified assumptions. Future research should consider a more general set of assumptions, as well as alternative market structures with

more downstream firms and an upstream oligopoly, in order to examine the impact of the information flow in different industry settings.

8. Further reading

De Bondt, 1996; Delbono and Denicolò, 1991; Katz and Ordover, 1990; Klass and Salinger, 1995; Krattenmaker and Salop, 1986; Motta, 1992; Reiffen and Vita, 1995; Willcox, 1995.

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Appendix

Proof of Proposition 1

(i) We calculate:

$$x_1^*(k) - x_2^*(k) = v \frac{3d^3\mu(4 - d) + 16\mu(3 - 2d - d^2) + 8k\phi}{D + L}$$

Since $D, L > 0$, $0 \leq k \leq 1$ and $0 \leq d < 1$, we have that $\varphi = 1 - d + d(1 - k) + 2\mu d(1 - d) > 0$, and thus that $x_1^*(k) > x_2^*(k)$.

(ii) Since $x_1^*(k) > x_2^*(k)$ and $w^*(k) > 0$, then we also have that $q_1^*(k) > q_2^*(k)$. \square

Proof of Proposition 2

(i) Let the equilibrium value $x_2^*(k)$ be defined by the intersection point of the two R&D reaction functions: $R_1(x_2^*(k), k) = R_2^{-1}(x_2^*(k), k)$, and let $k' > k$. The arrows in Fig. 2 indicate how the reaction functions move when k increases. An inspection of Fig. 2 reveals that $R_1(x_2^*(k), k') > R_1(x_2^*(k), k)$ and $R_2^{-1}(x_2^*(k), k) > R_2^{-1}(x_2^*(k), k')$, thus we know that $R_1(x_2^*(k)) > R_2^{-1}(x_2^*(k), k')$. In addition, we know that $R_2^{-1}(x_2(k), k)$ is downward sloping, while $R_1(x_2(k), k)$ is upward sloping for $k > k_{cr}$ and downward sloping for $k < k_{cr}$, but for all the values of k , $0 > dR_1/dx_2 > dR_2^{-1}/dx_2$. Hence, for $R_1(x_2^*(k'), k') = R_2^{-1}(x_2^*(k'), k')$ to hold, we must have $x_2^*(k') < x_2^*(k)$, i.e. $x_2^*(k)$ is decreasing in k .

(ii) To prove the second part of the Proposition, note that we know from (12) that $R_1(x_2, k) > R_1(x_2, 0)$ for all x_2 and $k > 0$. Since $R_1(x_2, 0)$ is downward sloping and

$x_2(0) > x_2(k)$, we have $R_1(x_2(k), 0) > R_1(x_2(0), 0)$. It follows that $R_1(x_2(k), k) > R_1(x_2(k), 0) > R_1(x_2(0), 0)$, i.e. $x_1(k) > x_1(0)$.¹⁵ Letting again $k' > k$, we know from (12) that $R_1(x_2(k), k') > R_1(x_2(k), k)$ for all x_2 and $k, k' < k_{cr}$. In addition, we know that $R_1(x_2(k), k)$ is downward sloping for $k < k_{cr}$ and that $x_2(k) > x_2(k')$. Hence, the following inequality $R_1(x_2(k'), k) > R_1(x_2(k), k)$ holds. From these two inequalities, it follows that $R_1(x_2(k'), k') > R_1(x_2(k), k')$, i.e. $x_1(k)$ is increasing in k for $k < k_{cr}$. In order to show that $x_1^*(k)$ is increasing in k , for $k \leq \max\{1, \tilde{k}\}$, we differentiate $x_1^*(k)$ with respect to k . Setting the derivative equal to zero, and solving for k , $\hat{k} = (1/8d)\{(8 - 3d^2)\sqrt{[(8 + d^2)2\mu - 8]\mu + 8 + (3d^4 + 16d^2 - 64)\mu}\}$ is obtained. It can be checked that $\hat{k} > k_{cr}$ for all d and μ and that $\hat{k} > 1$ for some parameter values (e.g. for d small enough). In this latter case $x_1^*(k)$ increases with k for all the values of k . \square

Proof of Proposition 3

Differentiating Eq. (16) with respect to k we obtain:

$$\frac{\partial w^*(k)}{\partial k} = 8\mu\nu(2\mu(1-d) - 1) \times \frac{8dk(2-dk) + 12(2-d^2) - \mu(8-3d^2)(2kd^3 - 5d^2 + 8)}{(D+L)^2}$$

The denominator of the above expression is always positive. The first part of the numerator, $8\mu\nu[2\mu(1-d) - 1]$, is positive under Assumption 1. As for the second part, it decreases with μ . Hence, it takes its highest value for the lowest possible μ , which from Assumption 1, equals $1/[2(1-d)]$. Substituting $\mu = 1/[2(1-d)]$ into the second part of the numerator we obtain:

$$\frac{2dk[16(1-d) + d^4 - 8d(d-dk+k)] - 16 - 5d^4 - 24(2+d)(1-d)}{2(1-d)}$$

This expression is always negative for $0 \leq k \leq 1$ and $0 \leq d < 1$, i.e. $w^*(k)$ decreases with k . \square

Proof of Proposition 4

(i) Differentiate Eq. (18) with respect to k and follow the same procedure as in Proposition 3.

(ii) For the first part, it is easy to check that the partial derivative of $q_1^*(k)$ with respect to k at $k=0$ is positive. In order to show that $q_1^*(k)$ is increasing in k , for $k \leq \max\{1, \tilde{k}\}$, we differentiate $q_1^*(k)$ with respect to k . Setting the derivative equal to zero and solving for k , we obtain the following: $\tilde{k} = (1/8d)(8 - (64 - 32d^2 + 3d^4)\mu + \sqrt{(8 - 3d^2)S})$, where $S = 8d^2 - 8(8 - 3d^2)\mu + (8 - d^2)^2(8 - 3d^2)\mu^2$. It can be checked that $\tilde{k} > k_{cr}$ for all d and μ . Moreover, it can be checked that $\tilde{k} > 1$ for some parameter values (e.g. for d small enough),

¹⁵ We thank an anonymous referee for suggesting this part of the proof.

in which case $q_1^*(k)$ increases with k for all values of k . To prove the second part, we calculate, for $0 < k \leq 1$:

$$q_1(k) - q_1(0) = \frac{(8 - d^2)(x_1(k) - x_1(0)) + 2d(x_2(0) - x_2(k)) + k(8 - d^2)x_2(k)}{2(8 - 3d^2)}$$

Since from Proposition 2 we have $x_1^*(k) > x_1^*(0)$ and $x_2^*(0) > x_2^*(k)$, it follows $q_1^*(k) > q_1^*(0)$. \square

Proof of Proposition 5

(i) We obtain the equilibrium profits of D_2 , $\pi_2^*(k)$, by substituting the equilibrium values, (14), (15), (16), (17), and (18), into (5). Differentiating $\pi_2^*(k)$ with respect to k the result follows.

(ii) Outline of the proof: we obtain the equilibrium profits of U- D_1 , $\pi_{v_1}^*(k)$, by substituting the equilibrium values, (14), (15), (16), (17), (18), into (4). Our task is to show that $\pi_{v_1}^*(k)$ is a quasi-concave function of k for $0 \leq k \leq 1$. For this purpose, we take the derivative of $\pi_{v_1}^*(k)$ with respect to k , which is given by the ratio N/D_1 , where $D_1 > 0$. The first step is to check that this derivative is positive at $k=0$, which implies that $N(0) > 0$. The second step is to show that the second derivative of N with respect to k , denoted by N_{kk} , is negative for all k . To show this, we demonstrate that it is negative for the minimum value of μ given by Assumption 1, we then show that the first derivative of N_{kk} with respect to μ is negative at the minimum value of μ , and finally that the second derivative of N_{kk} with respect to μ is negative for all μ . This implies that N_{kk} is initially negative and that it decreases, at an increasing rate, with μ . Hence, its maximum value is attained at the minimum value of μ , at which we already know that it is negative. This establishes that $\pi_{v_1}^*(k)$ is quasi-concave in k . The next step is to check whether $N(1)$ is positive or negative. When $N(1)$ is positive, a result which holds for small values of d , $\pi_{v_1}^*(k)$ is increasing in k for all $0 \leq k \leq 1$; hence, $\pi_{v_1}^*(k) > \pi_{v_1}^*(0)$, with $0 < k \leq 1$. On the other hand, when $N(1)$ is negative, we know that $\pi_{v_1}^*(k)$ is initially increasing and then decreasing in k . The final step is to show that $\pi_{v_1}^*(1) > \pi_{v_1}^*(0)$, which again implies that $\pi_{v_1}^*(k) > \pi_{v_1}^*(0)$, with $0 < k \leq 1$. \square

Proof of Proposition 6

Outline of the proof.¹⁶ We follow the same steps as in the proof of Proposition 5, part (ii), in order to show that $W(k)$ is quasi-concave in k for all $0 \leq k \leq 1$. Proceeding then in a similar manner, we find that, contrary to the above case, when μ and d are sufficiently high, $W(0) > W(1)$, while the opposite is true for all the other values. It follows that if $W(0) < W(1)$, welfare is higher under information flow. While if $W(0) > W(1)$, quasi-concavity implies that there exists a unique \bar{k} such that for all $k < \bar{k}$ welfare is higher under information flow ($k > 0$) than under a ‘firewall’ ($k = 0$) and vice versa for all $k > \bar{k}$, where \bar{k} solves $W(0) = W(\bar{k})$. Finally, in order to show that \bar{k} is decreasing in μ we proceed as follows. We show that both the first derivative of $W(k)$ with respect to μ , denoted by W_{μ} , at the minimum value of μ , and the

¹⁶ The detailed proofs of Proposition 5 and Proposition 6 are available from the author upon request.

second derivative of $W(k)$ with respect to μ , denoted by $W_{\mu\mu}$ are negative. The former can be checked directly. For the latter, we first prove that it is negative for the minimum value of μ and then that the third derivative of $W(k)$ with respect to μ , denoted by $W_{\mu\mu\mu}$ is negative. These two results imply that $W(k)$ is decreasing, at an increasing rate in μ , hence its maximum value is obtained at the minimum value of μ . \square

References

- d'Aspremont, C., Jacquemin, A., 1988. Cooperative and non-cooperative R&D in duopoly with spillovers. *American Economic Review* 78, 1133–1137.
- Banerjee, S., Lin, P., 2003. Downstream R&D, rising rivals' costs, and input price contracts. *International Journal of Industrial Organization* 21, 79–96.
- De Bondt, R., 1996. Spillovers and innovative activities. *International Journal of Industrial Organization* 15, 1–28.
- De Bondt, R., Slaets, P., Cassiman, B., 1992. The degree of spillovers and the number of rivals for maximum effective R&D. *International Journal of Industrial Organization* 10, 35–54.
- Delbono, F., Denicolò, V., 1991. Incentives to innovate in a Cournot oligopoly. *Quarterly Journal of Economics* 106, 951–961.
- Hughes, S.J., Kao, L.J., 2001. Vertical integration and proprietary information transmission. *Journal of Economics and Management Strategy* 10, 277–299.
- Kamien, M.I., Muller, E., Zang, I., 1992. Research joint ventures and R&D cartels. *American Economic Review* 82, 1293–1306.
- Katsoulacos, Y., Ulph, D., 1998. Endogenous spillovers and the performance of research joint ventures. *Journal of Industrial Economics* 46, 333–357.
- Katz, M.L., Ordover, J.A., 1990. R&D cooperation and competition. *Brookings Papers of Economic Activity Microeconomics* 137–203.
- Klass, M.W., Salinger, M., 1995. Do new theories of vertical foreclosure provide sound guidance for consent agreements in vertical merger cases? *The Antitrust Bulletin* Fall 667–694.
- Krattenmaker, T.G., Salop, S.C., 1986. Anticompetitive exclusion: raising rivals' costs to achieve power over price. *The Yale Law Journal* 96, 209–293.
- Milliou, C., 2001. Vertical integration and R&D spillovers: is there a need for 'firewalls'? *European University Institute Working Paper No. 2001/17*.
- Motta, M., 1992. Cooperative R&D and vertical product differentiation. *International Journal of Industrial Organization* 10, 643–662.
- Reiffen, D., Vita, M., 1995. Comment: is there new thinking on vertical mergers? *Antitrust Law Journal* 63, 917–941.
- Rey, P., Tirole, J., forthcoming. A primer on foreclosure. In: Armstrong, M., Porter, R.H. (Eds.), *Handbook of Industrial Organization*, vol. 3. North Holland, Amsterdam.
- Singh, N., Vives, X., 1984. Price and quantity competition in a differentiated duopoly. *Rand Journal of Economics* 15, 546–554.
- Thomas, C.J., 1996. Market structure and the flow of information in repeated auctions. *Bureau of Economics Working Paper No. 213*.
- Willcox, T.C., 1995. Behavioral remedies in a post-Chicago world: it's time to revise the merger guidelines. *The Antitrust Bulletin* Spring 227–256.