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Vertical Integration and R&D Spillovers: Is There a Need for 'Firewalls'?*

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Abstract

We investigate the impact of R&D spillovers on innovation incentives and welfare. In particular, we consider the case in which the spillovers are due to the information flow from a downstream nonintegrated firm to the downstream division of a vertically integrated firm via its upstream subsidiary. Using a simple model, in which both the integrated and nonintegrated firm engage in cost-reducing R&D and compete in quantities, we show that the impact of the R&D spillovers on innovation, output, and profits, is positive for the integrated firm, and negative for the nonintegrated firm. In the case of differentiated goods, our findings on welfare provide insights against the implementation of a 'firewall'.

JEL classification: L22, L11. L10, L49, K21

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1. Introduction

There is 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 the postacquisition firms. A new theory of anticompetitive activity seems to emerge from these consent decrees. This theory refers to the possible abuse of nonpublic information that could be obtained by a vertically integrated firm at one level of production to be misused at an adjacent level[1].

In particular, 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 entities. 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 the innovation incentives and the competition in the downstream market.

A necessary condition for these concerns to be raised is that important information, particularly information about the technology, the design or the specific qualities and characteristics of the products must be shared between the upstream and downstream firms. This condition seems to be satisfied in most of the R&D intensive industries, where the coordination of the upstream and downstream divisions, and hence the exchange of information about their products, is necessary in order for the products to be compatible, to avoid extra costs of adjustment, 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 industry sectors: defense (Raytheon/Chrysler, Boeing/Rockwell, Alliant/Hercules, Lockheed/Loral,), telecommunications (AT&T/McCaw, MCI/BT), pharmaceuticals (Merc/Medco), satellites (Boeing/General Motors, Martin Marietta/General Dynamics), and energy (PacifiCorp/Energy Group)[2]. In all the above cases, the upstream and downstream firms were working closely, and the upstream division of the merged entity was receiving nonpublic information about the products of its downstream customers in its capacity as an

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[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 and business 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.

upstream input supplier. Hence, the vertically integrated entity's division in the upstream market had the possibility of transferring this nonpublic information to its own downstream division. The consent decrees of the DOJ and the FTC, in all these cases, allowed the vertical mergers to take place. However, assuming that the information flow, among other things, would also reduce the firms' innovation incentives, required the erection 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 part of the integrated firm is asked to use the downstream competitor's proprietary information only in its capacity as its provider, and not to provide it, disclose it or otherwise make it available to its downstream division. 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 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.

A successful implementation of 'firewalls' should ease the concerns about the presumed harmful information flows. 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 the innovation incentives and the social welfare.

In our attempt to answer this question, we analyze 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 producer. A three-stage game is analyzed. At the first stage, both the integrated and the nonintegrated firm choose their level of cost-reducing R&D. At the second stage, the integrated firm chooses the wholesale price of the input. And at the third stage, the two firms produce differentiated goods and compete in quantities in the market for the final goods.

Our main findings show that the information flow between the different divisions of the integrated firm regarding the R&D efforts of the nonintegrated firm does not necessarily reduce the R&D incentives and welfare. Indeed, the reverse might be true. In particular, we show that the information flow leads to higher innovation incentives for the integrated firm, but to lower incentives for the nonintegrated firm. Respectively, the information flow has a positive impact on both the output and the profits of the integrated firm and a negative impact on the output and the profits of the independent firm. As for our findings regarding the social welfare consequences of the information flow, in the majority of the cases, they provide insights in favor of the information flow and hence against the implementation of a 'firewall'.

There is little economic research regarding the competitive effects of 'firewalls' following vertical integration. Thomas (1996) considering a market with duopoly in both upstream and downstream sectors, examines the impact on firm behavior and welfare of the information flow regarding the opponent's bids. He finds that both divisions of the integrated firm are indifferent about the transfer of information within the integrated firm. However, he shows that the nonintegrated downstream firm prefers a 'firewall' to the transfer of information between the divisions of the integrated firm, while the opposite holds for the nonintegrated upstream firm.

In a more recent paper, Hughes and Kao (2001) consider the consequences of information sharing within a vertical merger on competition and organizational structure, and assess the impact of 'firewalls' on social welfare. In their analysis, they consider a market structure with competition in both sides of the market, and they refer to the disclosure of the rival's private demand information. They find that while 'firewalls' increase the industry's profits, they decrease both consumer surplus and overall welfare. The former result implies that the upstream division of the integrated firm has no incentives to reveal information to its downstream subsidiary. Hence, in this framework, there is no reason for the information transmission concerns to be raised at the first place.

Notice that in both of these papers there is competition in the upstream market, which affects the incentives of the firms and hence their conclusions. In this sense, they differ from the present paper, where we concentrate in the case of an upstream monopoly in order to capture only the consequences of the information flow. 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, and hence they do not capture the latter's effect on innovation incentives and welfare. In our specification though we do, and thus these three papers complement each other.

The rest of the paper has the following structure. In Section 2, the model under consideration is described in detail. In Section 3, the equilibrium outcomes are characterized under different assumptions about the information flow. In Section 4, a comparative statics analysis is performed, and finally in Section 5, our main results are summarized and possible policy implications as well as extensions of our model and research are provided.

2. The 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

Figure 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 downstream.

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 z, which without loss of generality, we set equal to zero[3]. The downstream division of the integrated firm D_1 obtains the input from U at marginal cost z, while the nonintegrated downstream firm D_2 obtains it at a wholesale price w determined through profit-maximization. The two downstream firms, D_1 and D_2, undertake R&D investments and transform the input into the final good in a constant ratio. We normalize the units so that one unit of upstream output is used in one unit of downstream output. The vertically integrated firm U-D_1 and the nonintegrated downstream firm D_2 produce differentiated final goods and compete in quantities.

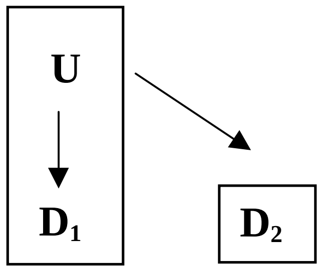

Figure 1
Partially vertically integrated industry

Under this setting, we analyze a three-stage sequential or "closed-loop" game, in which all past play is perfectly observable at the beginning of each stage:

- **First Stage.** The integrated firm U-D_1, and the nonintegrated one D_2, simultaneously and independently choose their R&D effort levels, x_1 and x_2, respectively.

- **Second Stage.** The integrated firm U-D_1 makes a "take-it-or-leave-it" offer to the nonintegrated downstream producer D_2 regarding the wholesale price w of the intermediate product.

- **Third Stage.** The integrated firm U-D_1 and the nonintegrated one D_2, produce differentiated goods and compete in quantities.

[3] "A 'bottleneck' firm's product cannot be cheaply duplicated by users who are denied access to it." (Rey and Tirole, 1996, p.1). We assume here that the possibility of bypassing the bottleneck supplier is so costly that it does not exist.

We assume Subgame Perfection throughout. In each stage of the game, each firm anticipates how its action will influence the actions of the rival firm at every future stage. Hence, both the choice of the R&D investments in the first stage of the game and of the wholesale price in the second stage, consist strategic choices.

In order to incorporate the effect of the information flow between the two production levels of the merged entity, we estimate the Subgame Perfect Nash Equilibrium under two different sets of assumptions regarding the information transfer. More specifically, we consider two different scenarios regarding the information flow between the different production levels of the vertically integrated firm. In the first scenario, we assume that there is no flow of nonpublic information, and in particular of information about the R&D undertaken by the nonintegrated downstream firm D_2, between the different divisions of the vertically integrated firm U-D_1. This scenario is in accordance with the nondisclosure requirement, the 'firewall' imposed through the consent decrees of the DOJ and the FTC. As a consequence of the 'firewall' imposed, there are no R&D spillovers from D_2 to the downstream division of the merged firm U-D_1. In the second scenario, we assume that the upstream monopolist, in the absence of a nondisclosure requirement, transmits to its downstream subsidiary the information that it has obtained about the R&D effort levels of its downstream rival through its vertical relation and conducts with it. We model this information scenario by assuming that there exist one-way R&D spillovers from the independent downstream producer D_2 to the downstream subsidiary of the bottleneck supplier D_1.

(a) Inverse Demand Functions

The inverse demand functions for the final product of the vertically integrated firm U-D_1 and of the nonintegrated downstream firm D_2 are respectively given by:

$$p_1 = a - q_1 - cq_2 \quad (1)$$

$$p_2 = a - q_2 - cq_1 \quad (2)$$

$$a > 0, \quad 1 > c > 0$$

The parameter c is the products' measure of differentiation. The products are highly differentiated if a change in the quantity of one product has a small or negligible effect on the price of the other product. Formally, the products are highly differentiated if c is close to 0. The products are almost homogeneous if a change in the quantity of one product has strong effects on the price of the other product. Formally, the products are almost homogeneous if c is close to 1.

(b) Cost Functions

Following the paper by d' Aspremont and Jacquemin (1988) and most of the subsequent literature on R&D cooperation, we consider the case where the R&D activities that the two firms undertake at the first stage of the game are cost-reducing. Formally, the cost function of the vertically integrated firm and of the nonintegrated firm are respectively given by:

$$C_1(x_1, x_2, q_1) = (A - x_1 - kx_2)q_1 \tag{3}$$

$$C_2(x_2, w, q_2) = (A + w - x_2)q_2 \tag{4}$$

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

If no R&D effort levels are undertaken, the unit costs of both firms are given by A. To simply notation we define $v = (a - A) > 0$. The parameter *k* is the degree of R&D spillovers. It reflects the extent to which knowledge about the R&D effort levels of the downstream producer D_2 leaks to D_1, as well as the productivity of the acquired knowledge in decreasing the production cost of the integrated firm's final product[4]. The degree of spillovers is equal to zero under both information scenarios in the unit cost function of the nonintegrated downstream producer, while it is positive for the integrated firm when there is Information Flow and zero when there is a 'firewall' established by the Antitrust Authorities between the two different production levels of the merged firm. Note that the 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 of the downstream division of the integrated firm U-D_1, and of the nonintegrated firm D_2, x_1 and x_2 respectively, are envisaged to be made with diminishing returns to scale reflected on the quadratic form of the cost of R&D investments:

$$\Gamma(x_i) = \mu \frac{x_i^2}{2}, \quad \mu > 0, \quad i = 1,2 \tag{5}$$

Equation (5) 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. A different interpretation of this assumption is that a higher cost parameter μ reflects a lower efficiency of the existing R&D technology, while a lower parameter μ reflects a higher efficiency of the existing R&D technology or improved technological opportunities.

[4] "The R&D process is supposed to involve trial and error. The individual firm's R&D activity does not involve following a single path. In an R&D process involving many possible paths and trial and error, it is unlikely that individual firms will pursue identical activities. Indeed, it is reasonable for each firm to pursue several avenues simultaneously, the differences among firms being in the greater emphasis each one places on one over the others." (Kamien, Muller , Zang, 1992, p. 1298)

In order to guarantee that the second order conditions are satisfied and that the firms choose strictly positive amounts of R&D, we make the following assumption:

Assumption 1: *The degree of differentiation c satisfies the following condition*[5]*:*

$$c < 1 - \frac{1}{2\mu}$$

Employing the above inverse demand and cost functions, we proceed by calculating the equilibrium outcomes under the two different information scenarios, under a "firewall" requirement, and under Information Flow, and then we perform a comparative statics analysis.

3. Equilibrium Outcomes

(a) Equilibrium Under a 'Firewall' Requirement

The profit functions of the integrated firm U-D_1 and of the nonintegrated one D_2 are respectively given by:

$$\pi_{VIF} = w_F q_{2F} + (a - q_{1F} - cq_{2F})q_{1F} - (A - x_{1F})q_{1F} - \mu \frac{x_{1F}^2}{2} \tag{6}$$

$$\pi_{2F} = (a - q_{2F} - cq_{1F})q_{2F} - (A + w_F - x_{2F})q_{2F} - \mu \frac{x_{2F}^2}{2} \tag{7}$$

Both functions (6) and (7) are strictly concave in R&D under Assumption 1. Notice that the profit of the vertically integrated firm comes from the two markets, upstream and downstream, in which the firm operates.

Starting from the last stage of the game, we differentiate (6) with respect to q_{1F} and (7) with respect to q_{2F}, and we obtain the quantity best response functions of the two firms:

$$R_1^F(q_{2F}) = \frac{v + x_{1F} - cq_{2F}}{2} \tag{8}$$

$$R_2^F(q_{1F}) = \frac{v - w_F + x_{2F} - cq_{1F}}{2} \tag{9}$$

Note that the best response functions are downward sloping, hence the quantities are strategic substitutes for both firms.

Solving (8) and (9), we find the Cournot-Nash equilibrium quantities of the two final products in terms of the wholesale price w_F and the R&D effort levels, x_{1F} and x_{2F}:

[5] See Appendix for the derivation of this condition. Note that this assumption is a consequence of the market foreclosure outcome when the goods are homogenous ($c = 1$).

$$q_{1F}(w_F, x_{1F}, x_{2F}) = \frac{v(2-c) + cw_F - cx_{2F} + 2x_{1F}}{4-c^2} \tag{10}$$

$$q_{2F}(w_F, x_{1F}, x_{2F}) = \frac{v(2-c) - 2w_F - cx_{1F} + 2x_{2F}}{4-c^2} \tag{11}$$

Since in the preceding stage the integrated firm U-D_1 chooses the wholesale price w_F at which it provides the input to D_2, we solve for its optimal value in terms of the R&D effort levels, after rewriting the profit function of the integrated firm using the equilibrium outputs:

$$w_F(x_{1F}, x_{2F}) = \frac{v(c^3 + 8 - 4c^2) + c^3 x_{1F} + 4x_{2F}(2-c^2)}{2(8-3c^2)} \tag{12}$$

Moving to the first stage of the game, the first order conditions with respect to the R&D effort levels yield the following reaction functions of the two firms:

$$R_1^F(x_{2F}) = \frac{v(8-4c+c^2) - 4cx_{2F}}{2\mu(8-3c^2) - (8+c^2)} \tag{13}$$

$$R_2^F(x_{1F}) = 8\frac{v(1-c) - cx_{1F}}{\mu(8-3c^2)^2 - 8} \tag{14}$$

It is easy to verify from these reaction functions that the innovation investments are strategic substitutes for both the integrated and the nonintegrated firm.

From (13) and (14) we obtain the optimal R&D effort levels that both firms choose simultaneously:

$$x_{1F} = v\frac{\mathrm{B}}{\mathrm{D}} \quad (15) \qquad x_{2F} = 8v\frac{\mathrm{E}}{\mathrm{D}} \quad (16)$$

with $\mathrm{E} = 2\mu(1-c) - 1 > 0$

$\mathrm{B} = \mu[16(4-2c-c^2) + 3c^3(4-c)] - 8 > 0$

$\mathrm{D} = \mu\left[2\mu(8-3c^2)^2 - 16(5-c^2) + 3c^4\right] + 8 > 0$

It is worth mentioning that the integrated firm undertakes higher R&D and output levels than the nonintegrated firm. A result that reflects its competitive advantage towards the nonintegrated firm which has to pay a higher price in order to obtain the input from the upstream monopolist U. This result is formally presented in the following Proposition:

Proposition 1: *Under a 'firewall' requirement,*

(i)the R&D effort levels of the integrated firm exceed the R&D effort levels of the nonintegrated firm

$$x_{1F} > x_{2F}$$

(ii)the output of the integrated firm exceeds the output of the nonintegrated firm

$$q_{1F} > q_{2F}$$

Proof:

(i)In order to compare the equilibrium R&D effort levels of the two firms, (15) and (16), we calculate their difference:

$$x_{1F} - x_{2F} = v\frac{\text{B} - 8\text{E}}{\text{D}}$$

where $\text{D} > 0$ and $\text{B} - 8\text{E} = 3c^3\mu(4-c) + 16\mu(3-c-c^2) > 0$, since $1 > c > 0$. Hence, our result, $x_{1F} > x_{2F}$, follows.

(ii) We express the output levels of the two firms, (10) and (11), in terms of their R&D investments:

$$q_{1F}(x_{1F}, x_{2F}) = \frac{v(8-2c-c^2) + x_{1F}(8-c^2) - 2cx_{2F}}{2(8-3c^2)} \tag{17}$$

$$q_{2F}(x_{2F}, x_{1F}) = 2\frac{v(1-c) + x_{2F} - cx_{1F}}{(8-3c^2)} \tag{18}$$

In order to compare q_{1F} and q_{2F}, we calculate their difference:

$$q_{1F} - q_{2F} = \frac{\beta v + \zeta x_{1F} - \delta x_{2F}}{2(8-3c^2)}$$

where $\beta = 4(2+c) - c^2 > 0$, $\zeta = 12 - c^2 > 0$, and $\delta = 2(2+c) > 0$. Since $\zeta > \delta$, $1 > c > 0$, and $x_{1F} > x_{2F}$ from part (i), then $q_{1F} > q_{2F}$ follows. o

Finally, employing the equilibrium R&D effort levels, (15) and (16) in (12), (17) and (18), we obtain the optimal values of the wholesale price and quantities:

$$w_F = \mu v\frac{\text{F}}{\text{D}} \quad (19), \qquad q_{1F} = \mu v\frac{\text{G}}{\text{D}} \quad (20), \qquad q_{2F} = 2\mu v\frac{\text{H}}{\text{D}} \quad (21)$$

with $\text{F} = \mu[8(8-7c^2+c^3) + 3c^4(4-c)] - 4(8+2c-3c^2) > 0$

$\text{G} = \mu[16(4-c-2c^2) + 3c^3(2+c)] - 8(1+c) + 3c^3 > 0$

$\text{H} = (8-3c^2)[2\mu(1-c) - 1] > 0$

(b) Equilibrium under Information Flow

In this section, we compute the equilibrium outcomes in the case of one-way R&D spillovers from the independent downstream firm D_2, to the downstream division of the vertically integrated firm U-D_1, due to the Information Flow. Formally, the degree of R&D spillovers in the cost function of the integrated firm U-D_1 (3) is now greater than zero, $k > 0$.

The profit functions of the integrated firm U-D_1 and of the nonintegrated one D_2 are strictly concave in R&D under Assumption 1 and are respectively given by:

$$\pi_{VII} = w_I q_{2I} + (a - q_{1I} - cq_{2I})q_{1I} - (A - x_{1I} - kx_{2I})q_{1I} - \mu\frac{x_{1I}^2}{2} \tag{22}$$

$$\pi_{2I} = (a - q_{2I} - cq_{1I})q_{2I} - (A + w_I - x_{2I})q_{2I} - \mu\frac{x_{2I}^2}{2} \tag{23}$$

The first order conditions with respect to q_{1I} and q_{2I} give rise to the following quantity reaction functions:

$$R_1^I(q_{2I}) = \frac{v + x_{1I} + kx_{2I} - cq_{2I}}{2} \tag{24}$$

$$R_2^I(q_{1I}) = \frac{v - w_I + x_{2I} - cq_{1I}}{2} \tag{25}$$

Solving for the Cournot-Nash equilibrium quantities of the final goods produced by U-D_1 and D_2 respectively, we obtain:

$$q_{1I}(w_I, x_{1I}, x_{2I}) = \frac{v(2-c) + cw_I - cx_{2I} + 2kx_{2I} + 2x_{1I}}{4 - c^2} \tag{26}$$

$$q_{2I}(w_I, x_{2I}, x_{1I}) = \frac{v(2-c) - 2w_I - cx_{1I} + 2x_{2I} - ckx_{2I}}{4 - c^2} \tag{27}$$

Substituting (26) and (27) in the profit function of the integrated firm (22), and solving for the profit maximizing wholesale price w_I, we find:

$$w_I(x_{1I}, x_{2I}) = \frac{v(8 - 4c^2 + c^3) + c^3 x_{1I} + x_{2I}\left[kc^3 + 4(2 - c^2)\right]}{2(8 - 3c^2)} \tag{28}$$

Moving to the first stage of the game, we rewrite the profit functions of both firms using the equilibrium wholesale price and quantities given above, and differentiating them with respect to x_{1I} and x_{2I}, we obtain the R&D reaction functions of the two firms:

$$R_1^I(x_{2I}) = \frac{v(8 - 4c + c^2) - 4cx_{2I} + kx_{2I}(8 + c^2)}{2\mu(8 - 3c^2) - (8 + c^2)} \tag{29}$$

$$R_2^I(x_{1I}) = 8\frac{v(1-c) - cx_{1I} - vck(1-c) + c^2kx_{1I}}{\mu(8 - 3c^2)^2 - 8 + 8ck(2 - ck)} \tag{30}$$

Note that under Information Flow, the R&D effort levels continue to be strategic substitutes for the nonintegrated firm D_2, while for the integrated firm U-D_1 the nature of its R&D effort levels depends on the degree of spillovers. That is, the R&D investments are strategic substitutes (complements) only for low (high) degree of spillovers, in particular when the degree of spillovers k is smaller (greater) than $4c/(8 + c^2)$.

Using the two reaction functions, (29) and (30), the optimal R&D effort levels that the two firms choose at the first stage of the game are obtained:

$$x_{1I} = v\frac{\mathrm{B} + \mathrm{K}}{\mathrm{D} + \mathrm{L}} \tag{31}$$

$$x_{2I} = 8v\frac{(1 - ck)\mathrm{E}}{\mathrm{D} + \mathrm{L}} \tag{32}$$

with $\mathrm{K} = 8k\left[1 + c(1-k)\right] > 0$

$\mathrm{L} = 8ck\left[2\mu(2 - ck) - 1\right] > 0$

Similarly to the case of a ‘firewall’ requirement, we note that both the R&D effort levels and the output of the integrated firm are higher than those of the nonintegrated firm, capturing once again the cost advantage of the integrated downstream firm. These two results are formally presented in the following Proposition:

Proposition 2: *Under Information Flow,*
(i)the R&D effort levels of the integrated firm exceed the R&D effort levels of the nonintegrated firm

$$x_{1I} > x_{2I}$$

(ii)the output of the integrated firm exceeds the output of the nonintegrated firm

$$q_{1I} > q_{2I}$$

Proof:
(i)We calculate the difference of the R&D effort levels of the two firms:

$$x_{1I} - x_{2I} = \frac{3c^3\mu(4-c) + 16\mu(3-2c-c^2) + 8k\varphi}{\mathrm{D}+\mathrm{L}}$$

where $\mathrm{D},\mathrm{L} > 0$ and $\varphi = 1-c+c(1-k)+2\mu c(1-c) > 0$, since $1 > c > 0$, and $0 < k \leq 1$. Hence, $x_{1I} > x_{2I}$.
(ii) We express the equilibrium output levels of the two firms in terms of the R&D investments:

$$q_{1I} = \frac{v(8-2c-c^2) + x_{1I}(8-c^2) - 2cx_{2I} + kx_{2I}(8-c^2)}{2(8-3c^2)} \tag{33}$$

$$q_{2I} = 2\frac{v(1-c) - cx_{1I} + x_{2I} - ckx_{2I}}{(8-3c^2)} \tag{34}$$

In order to compare the output levels of the two firms, we calculate their difference:

$$q_{1I} - q_{2I} = \frac{\beta v + \zeta x_{1I} - \delta x_{2I} + \zeta k x_{2I}}{2(8-3c^2)}$$

Since we know from before that $\zeta > \delta > 0$, $x_{1I} > x_{2I}$, and $0 < k \leq 1$ by definition, then we also have $q_{1I} > q_{2I}$. o

Finally, using the optimal R&D effort levels (31) and (32), the equilibrium wholesale price of the intermediate product and the optimal quantities of the final good produced by the integrated and nonintegrated firm are obtained:

$$w_I = \mu v \frac{\mathrm{F} + c\mathrm{K}}{\mathrm{D}+\mathrm{L}} \tag{35}$$

$$q_{1I} = \mu v \frac{\mathrm{G}+\mathrm{K}}{\mathrm{D}+\mathrm{L}} \tag{36}$$

$$q_{2I} = 2\mu v \frac{\mathrm{H}}{\mathrm{D}+\mathrm{L}} \tag{37}$$

with F, K, D, L, G, and H defined as before.

4. Comparative Statics

In this part of the paper we compare the equilibrium outcomes that we have obtained under the two different information scenarios, in order to evaluate the effect of the information flow on innovation investments, output, firm performance, and social welfare.

(a) The Effect of Information Flow on Innovation Investments

We start by comparing the innovation levels of each firm under a 'firewall' requirement with those under Information Flow. In accordance with the presumptions of the Antitrust Authorities, we find that the Information Flow has a negative impact on the innovation incentives of the nonintegrated firm. In other words, the nonintegrated firm undertakes lower R&D effort levels when there is Information Flow than when there is a 'firewall' built between the two different divisions of the integrated firm. 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 this, and with the expectations of the Antitrust Authorities, we find that the Information Flow has a positive effect on the R&D levels of the vertically integrated firm. That is, the integrated firm undertakes higher R&D levels under Information Flow than under a 'firewall' requirement. Intuitively, the R&D spillovers reduce the costs of the integrated firm; such a reduction leads to an increase in output and in turn this increase in output reinforces the value of the cost reduction, inducing an increase in its own R&D investments. These two results are formally summarized in the following Proposition:

Proposition 3:
(i) The R&D effort levels of the nonintegrated firm are lower under Information Flow than under a 'firewall' :

$$x_{2I} < x_{2F}$$

(ii) The R&D effort levels of the integrated firm are higher under Information Flow than under a 'firewall':

$$x_{1I} > x_{1F}$$

Proof:
(i) From our previous analysis x_{2I} and x_{2F} are respectively given by:

$$x_{2I} = 8v\frac{(1-ck)\mathrm{E}}{\mathrm{D}+\mathrm{L}} \quad (32) \qquad x_{2F} = 8v\frac{\mathrm{E}}{\mathrm{D}} \quad (16)$$

Since D, L, E > 0, $0 < c < 1$, $0 < k \leq 1$, and $v > 0$, the numerator of x_{2I} is smaller than that of x_{2F}, while its denominator is larger, hence $x_{2I} < x_{2F}$.
(ii) The R&D reaction functions of the integrated firm under Information Flow and under a 'firewall' are respectively given by:

$$R_1^I(x_{2I}) = \frac{v(8-4c+c^2) - 4cx_{2I} + kx_{2I}(8+c^2)}{2\mu(8-3c^2)-(8+c^2)} \quad (29)$$

$$R_1^F(x_{2F}) = \frac{v(8-4c+c^2) - 4cx_{2F}}{2\mu(8-3c^2)-(8+c^2)} \quad (13)$$

The denominator of the above expressions is positive under assumption 1. Since we have from (i) that $x_{2I} < x_{2F}$ and since $k(8+c^2) > 0$, the numerator of $R_1^I(x_{2I})$ is greater than the numerator of $R_1^F(x_{2F})$. Hence, $R_1^F(x_{2F})$ is steeper than $R_1^I(x_{2I})$, and our result $x_{I1} > x_{1F}$ follows. o

Our next step is to evaluate the impact of the Information Flow on the total effective R&D, in other words on the unit cost-reductions caused by the R&D investments undertaken by the whole downstream industry, Unfortunately, we can not demonstrate closed form solutions for the general case. We are able though to compare the total effective innovation investments undertaken under Information Flow with that under a 'firewall' requirement, $x_{IE} - x_{FE} = [x_{1I} + (1+k)x_{2I}] - (x_{1F} + x_{2F})$, by considering a set of different values for the parameter μ, $\mu \in \{5,6,...,10\}$ and to obtain some useful and intuitive results. We find that the industry's effective R&D is higher under Information Flow than under a 'firewall', with the exception of the cases in which the products tend to be homogeneous and the rate of spillovers is high. In other words, the Information Flow has a positive effect on the total innovation incentives when the final goods are not very close substitutes. This result is illustrated in Figure 2 below for μ = 5 and μ =10. In the area lying above the curve, the total effective R&D under a 'firewall' exceeds that under Information Flow, while the opposite holds for the area below the curve.

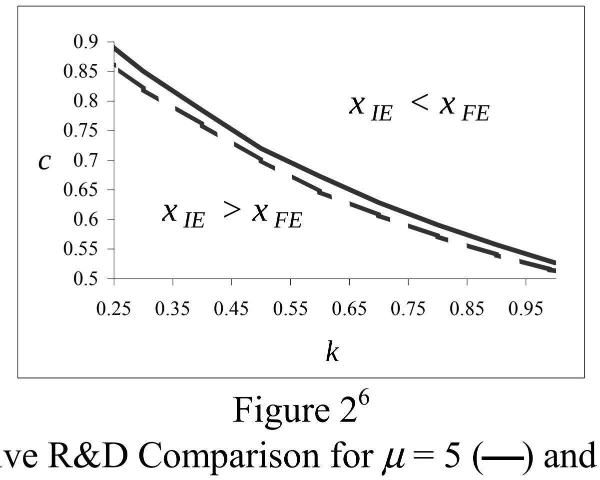

Figure 2[6]

Total Effective R&D Comparison for μ = 5 (—) and μ = 10 (– –)

[6] Under Assumption 1, by setting μ = 5 and μ = 10 we can consider a wide range of values for the degree of differentiation c. In particular: $0 < c < .9$ and $0 < c < .95$ respectively.

Note that for a given degree of differentiation c, the higher the rate of spillovers k, the better are 'firewalls'. Similarly, for a given rate of spillovers k, the closer substitutes the goods are, the higher the total R&D is with 'firewalls' than with Information Flow. The intuition behind this result is that in the case of Information Flow, the incentives of the downstream firm to undertake R&D decrease as the rate of spillovers increases and at the same time, the closer substitutes the goods are, and hence the fiercer the competition, the stronger the negative impact of the lack of full appropriability on its R&D investments. Note also, that the positive effect of the Information Flow on the total effective R&D decreases with the cost parameter μ. That is, the higher the cost of R&D, the fewer the cases in which the effective R&D under Information Flow exceeds that under a 'firewall'.

Summarizing, the Information Flow scenario leads to higher innovation investments for the integrated firm, but lower investments for its nonintegrated rival. In addition, it increases the effective total R&D investments of the downstream industry, with the exception of the cases in which the final goods tend to be homogeneous and the rate of spillovers is high.

(b) The Effect of Information Flow on Output

Since the strategic investments in R&D allow firms to reduce their unit production costs, an increase (decrease) in the R&D investments of a firm either because of the Information Flow or because of a change in the spillovers rate, should respectively lead to an increase (decrease) in the firm's output.

However, a change in the wholesale price of the input might also affect the level of output chosen by the downstream firms. Comparing the wholesale price under the two different information scenarios, we find that the wholesale price under a 'firewall' is higher than that under Information Flow (see Remark 1 below). The rationale behind this last result is that in the case of Information Flow the upstream division of the integrated firm on the one hand has incentives to charge a higher wholesale price in order to squeeze the downstream independent firm and hence to improve the position of its downstream subsidiary, but on the other hand it has incentives to charge a low wholesale price in order to promote the R&D investments of the independent downstream so that its subsidiary can free ride on them. While in the case of 'firewalls' the upstream division of the integrated firm has only incentives to squeeze the independent firm, since the possibility of R&D spillovers does not exist.

Remark 1: *The wholesale price of the input under 'firewall',* w_F *, exceeds that under Information Flow,* w_I*.*

The decrease in the wholesale price in the absence of a 'firewall' reduces the cost advantage of the downstream integrated firm and at the same time improves the competitive position of the nonintegrated downstream firm. In the end, the first effect, the effect of the change in R&D levels, dominates the effect of the wholesale price, 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. To verify this effect it is convenient to use the output produced by the two firms expressed as function of their R&D effort levels, after having substituted for the wholesale price. From our previous analysis, we have equations (17) and (18) for the output of the two firms in the case of a ‘firewall’ requirement, and equations (33) and (34) in the case of Information Flow:

$$q_{1F}(x_{1F}, x_{2F}) = \frac{v(8-2c-c^2) + x_{1F}(8-c^2) - 2cx_{2F}}{2(8-3c^2)} \tag{17}$$

$$q_{2F}(x_{2F}, x_{1F}) = 2\frac{v(1-c) + x_{2F} - cx_{1F}}{(8-3c^2)} \tag{18}$$

$$q_{1I}(x_{1I}, x_{2I}) = \frac{v(8-2c-c^2) + x_{1I}(8-c^2) - 2cx_{2I} + kx_{2I}(8-c^2)}{2(8-3c^2)} \tag{33}$$

$$q_{2I}(x_{1I}, x_{2I}) = 2\frac{v(1-c) - cx_{1I} + x_{2I} - ckx_{2I}}{(8-3c^2)} \tag{34}$$

Note that in the case of a ‘firewall’ an increase in cost-reducing R&D by the nonintegrated firm D_2 (integrated firm U-D_1) increases the equilibrium output of D_2 (U-D_1), while an increase in the R&D of its rival firm U-D_1 (D_2) decreases the output of D_2 (U-D_1). In the case of Information Flow though, due to the one-way R&D spillovers, an increase in cost-reducing R&D by firm D_2 has two conflicting effects on the equilibrium output of firm U-D_1. On the one hand, it tends to increase U-D_1’s output by bringing U-D_1’s cost down through the spillovers of the cost-reducing benefits. On the other hand, it tends to decrease U-D_1’s output by strengthening D_2’s competitive edge against U-D_1. The following Proposition is a consequence of these remarks and of Proposition 3:

Proposition 4:

(i) The output of the nonintegrated firm is lower under Information Flow than under a ‘firewall’:

$$q_{2I} < q_{2F}$$

(ii) The output of the integrated firm is higher under Information Flow than under a ‘firewall’:

$$q_{1I} > q_{1F}$$

Proof:

(i) In order to compare q_{1I} and q_{1F}, we calculate their difference:

$$q_{1I} - q_{1F} = \frac{(8-c^2)(x_{1I} - x_{1F}) + 2c(x_{2F} - x_{2I}) + kx_{2I}(8-c^2)}{2(8-3c^2)}$$

Since from Proposition 3 we have $x_{1I} > x_{1F}$, $x_{2F} > x_{2I}$, and by definition $0 < k \leq 1$, then we also have $q_{1I} > q_{1F}$.

(ii) In order to compare q_{2I} and q_{2F}, we calculate their difference:

$$q_{2I} - q_{2F} = -2\frac{c(x_{1I} - x_{1F}) + (x_{2F} - x_{2I}) + ckx_{2I}}{8 - 3c^2}$$

Since from Proposition 3 we have $x_{1I} > x_{1F}$, $x_{2F} > x_{2I}$, and by definition $0 < k \leq 1$, then $q_{2I} < q_{2F}$ also follows. o

Next we consider the impact of the Information Flow on the output of the whole downstream industry. Unfortunately, once again we can not demonstrate closed form solutions for the general case. We compare though the total output produced under Information Flow with that under a 'firewall', $q_I - q_F = (q_{1I} + q_{2I}) - (q_{1F} + q_{2F})$, by setting different values for the parameter $\mu, \mu \in \{5,6,...,10\}$. By doing so, we find that the industry's total output is higher under Information Flow than under a 'firewall', with the exception of the cases in which the final products tend to be homogeneous and the degree of spillovers is very high. This result is illustrated in Figure 3 below for μ = 5 and μ = 10. Similarly to the case of the innovation investments, we see that for a given degree of differentiation *c*, the higher the rate of spillovers *k*, the worse is the Information Flow relative to the 'firewalls'. Moreover, for a given rate of spillovers *k*, the closer substitutes the goods are, the lower the aggregate output with Information Flow than with 'firewalls'.

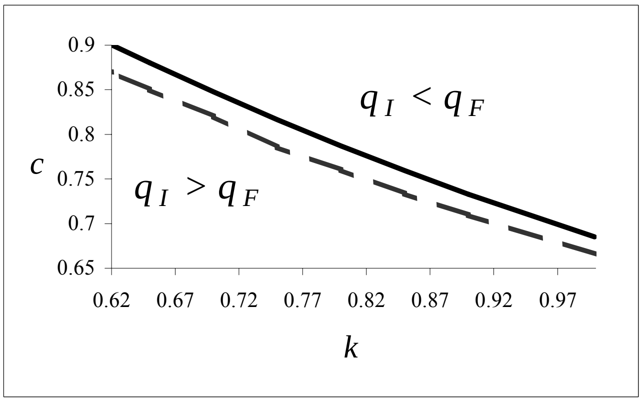

Figure 3
Total Quantity Comparison for μ = *5* (—) and μ = *10* (– –)

Note that the cases under which the total quantity under a 'firewall' exceeds the total quantity under Information Flow are fewer than those in which the effective R&D under a 'firewall' is higher than that under Information Flow. The explanation behind this difference lies on the impact of the wholesale price. As mentioned earlier, the wholesale price under a 'firewall' is higher than that under Information Flow, while the total output is decreasing in the wholesale price.

Summarizing, according to Proposition 4, the Information Flow increases the output of the integrated firm, while it suppresses the output of the independent firm, reflecting its analogous impact on their unit production costs. At the same time, the aggregate output is greater under Information Flow than under a ‘firewall’, with the exception of the cases in which the final goods are very close substitutes and the rate of spillovers is high.

(c) The Effect of Information Flow on Firms’ Profits and Welfare

Having examined how the Information Flow influences the R&D investments and the output, we turn to evaluate its impact on firms’ profits and social welfare. We start by considering the impact of the Information Flow on the profits of both the integrated and the nonintegrated firm, by setting again different values for the parameter $\mu, \mu \in \{5,6,...,10\}$. In the absence of a ‘firewall’ requirement, we find that the increase in the R&D investments and the output of the downstream integrated firm more than offsets the upstream unit’s loss caused by the reduction in the wholesale price. The net effect thus is an increase in the profits of the integrated firm due to the Information Flow. This result comes in contrast with the result of Hughes and Kao (2001) and 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. With respect to the profits of the downstream nonintegrated firm, the loss from the decrease in its R&D and output offsets the gains from the decrease in the wholesale price. Hence, the Information Flow leads to a decrease in the profits of the nonintegrated downstream producer.

On the aggregate level, the positive effect of the Information Flow on the profits of the integrated firm dominates the negative effect on the profits of the nonintegrated firm. In other words, the industry profits under Information Flow exceed those under a ‘firewall’. However, we note that their difference decreases as the measure of the R&D efficiency μ increases. That is, the higher the cost of R&D, the lower the positive impact of the Information Flow on the aggregate profits.

In order to check if from a social welfare point of view, Information Flow is preferable or not, we compare the total welfare level under Information Flow, with that under a ‘firewall’ requirement. Defining total welfare as the sum of the producers’ surplus and the consumers’ surplus, welfare under a ‘firewall’, and under Information Flow is respectively given by:

$$W_F = PS_F + CS_F = \pi_{VIF} + \pi_{2F} + \frac{1}{2}(q_{1F}^2 + q_{2F}^2) + cq_{1F}q_{2F} \quad (38)$$

$$W_I = PS_I + CS_I = \pi_{VII} + \pi_{2I} + \frac{1}{2}(q_{1I}^2 + q_{2I}^2) + cq_{1I}q_{2I} \quad (39)$$

As noted above, the Information Flow has a positive effect on the producer surplus. At the same time, we find that the Information Flow has also a positive effect on the consumer surplus, with the exception of the cases that the final goods tend to become perfect substitutes (for $k = 1$, $c > .79$ when $\mu = 5$ and $c > .765$ when $\mu = 10$) and there is a high rate of spillovers (for $c = .9$, $k > .77$ when $\mu = 5$ and $k > .67$ when $\mu = 10$). Similarly to the case of the aggregate profits, the difference in the consumer surplus decreases with μ. Hence, the higher the cost of R&D, the more the cases that the Information Flow has a negative impact on consumer surplus.

The net effect of the Information Flow on social welfare depends on the cost parameter μ, the degree of product differentiation c, and the rate of spillovers k. For small values of μ, e.g. $\mu = 5$, the welfare under Information Flow always exceeds that under a 'firewall'. While for higher values of μ, e.g. $\mu = 8, 9, 10$, the above result is true for the majority of the cases, but not always (see Figure 4 above). In particular, there is a very limited number of cases, where the welfare under 'firewalls' is higher than that under Information Flow. This holds only for the cases that the goods are almost homogeneous and the degree of spillovers is very high (for $\mu = 10$, $c > .84$ when $k = .99$, and $k > .926$ when $c = .949$).

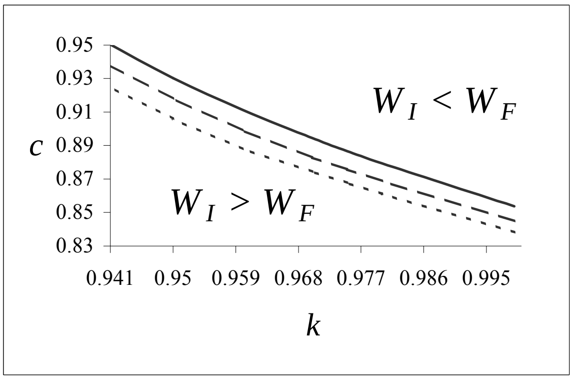

Figure 4
Welfare Comparison for $\mu = 8$ (—), $\mu = 9$ (– –) and $\mu = 10$ (- -)

Finally, we note that the positive effect of the Information Flow on welfare increases not only as the cost of R&D decreases, but also as the final goods become more and more differentiated. That is, for a given level of R&D spillovers, the more differentiated the goods become, the better is Information Flow relative to a 'firewall' requirement.

Summarizing, we have three main results in this section. First, that the profits of the integrated firm increases with the Information Flow, while the profits of its rival decreases. Second, that the industry profits are higher under Information Flow than under a 'firewall'. And third, that the impact of the Information Flow on total welfare is positive, with the exception of the cases in which the R&D investments are not very efficient (μ is high), the goods are almost homogeneous and the rate of spillovers is high.

5. Conclusions

We have examined the impact of the Information Flow on R&D incentives and welfare in a partially vertically integrated industry. To do so, we have used a simple model, in which a vertically integrated firm has the monopoly in producing the input in the upstream market and at the same time competes with a nonintegrated firm in the market for the final output. Both firms undertake cost-reducing R&D investments, produce differentiated goods and compete in quantities.

We have found that the Information Flow between the different divisions of the vertically integrated firm, regarding the R&D efforts of its downstream rival, increases the innovation incentives of the integrated entity, while it decreases the incentives of the nonintegrated firm. In addition the Information Flow leads to higher output and profits for the integrated firm, while it suppresses the output and the profits of the nonintegrated firm. The impact of the Information Flow on the R&D of the whole downstream industry is positive when we consider the total effective R&D, with the exception this time of the cases in which the final goods tend to be homogeneous and the spillovers are high. The same result holds for the aggregate output. With respect to the welfare consequences of the Information Flow, our findings seem to indicate that the Information Flow is desirable in the majority of the cases, and hence they provide insights against the policy intervention and the implementation of 'firewalls' when the final goods are not very close substitutes or when the R&D spillovers are not very high.

However, before any policy conclusions be taken too literally, we had better recall that our stated results depend upon very simplified assumptions. Future research should consider a more general set of assumptions, as well as a larger number of downstream firms, product innovation and price competition, in order to check the robustness of our results to the number of firms, and to the type of innovation and competition.

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Appendix

Second Order Conditions

In the case of 'firewalls' the second order conditions require:

$$\frac{\partial^2 \pi_{VIF}}{\partial x_{1F}^2} = \frac{8+c^2-2\mu(8-3c^2)}{2(8-3c^2)} < 0 \quad (1)$$

$$\frac{\partial^2 \pi_{2F}}{\partial x_{2F}^2} = \frac{8-\mu(8-3c^2)^2}{(8-3c^2)^2} < 0 \quad (2)$$

Hence, we must have:

$$\mu > \frac{8+c^2}{2(8-3c^2)} \quad (3)$$

In the case of Information Flow the second order conditions require:

$$\frac{\partial^2 \pi_{VII}}{\partial x_{1I}^2} = \frac{8+c^2-2\mu(8-3c^2)}{2(8-3c^2)} < 0 \quad (4)$$

$$\frac{\partial^2 \pi_{2I}}{\partial x_{2I}^2} = \frac{8(1-ck)^2-\mu(8-3c^2)^2}{(8-3c^2)^2} < 0 \quad (5)$$

Hence, we must have:

$$\mu > \frac{8(1-ck)^2}{(8-3c^2)^2} \quad (6)$$

Note that condition (3) is stronger than condition (6), hence (3) is sufficient for the profit functions of both firms to be strictly concave in R&D under the two different information scenarios.

Non-negativity Conditions For R&D

In the case of 'firewalls', we have from our analysis (see Section 3a) that the equilibrium R&D levels undertaken by the integrated and nonintegrated are respectively given by:

$$x_{1F} = v\frac{\mathrm{B}}{\mathrm{D}} \quad (7) \qquad x_{2F} = 8v\frac{\mathrm{E}}{\mathrm{D}} \quad (8)$$

where $\mathrm{E} = 2\mu(1-c) - 1$

$$\mathrm{B} = \mu[16(4-2c-c^2) + 3c^3(4-c)] - 8$$

$$\mathrm{D} = \mu\left[2\mu(8-3c^2)^2 - 16(5-c^2) + 3c^4\right] + 8$$

The denominator of both (7) and (8) is positive for:

$$\mu > \frac{80 - 16c^2 - 3c^4 \pm \sqrt{2304 + 512c^2 - 800c^4 + 96c^6 + 9c^8}}{4(8-3c^2)^2} \qquad (9)$$

The numerator of (7) is positive for:

$$\mu > \frac{8}{16(4-2c-c^2) + 3c^3(4-c)} \qquad (10)$$

The numerator of (8) is positive for:

$$\mu > \frac{1}{2(1-c)} \qquad (11)$$

Comparing conditions (9), (10) and (11), we note that condition (11) is stronger and hence it is sufficient for the two firms to undertake positive R&D levels under a ‘firewall’.

In the case of Information Flow the R&D effort levels of the integrated and nonintegrated firm are respectively given by (see Section 3b):

$$x_{1I} = v\frac{\mathrm{B}+\mathrm{K}}{\mathrm{D}+\mathrm{L}} \quad (12) \qquad x_{2I} = 8v\frac{(1-ck)\mathrm{E}}{\mathrm{D}+\mathrm{L}} \quad (13)$$

where $\mathrm{K} = 8k\left[1 + c(1-k)\right]$

$$\mathrm{L} = 8ck\left[2\mu(2-ck) - 1\right]$$

Both (12) and (13) are positive under condition (11) above. Note also that condition (11) is stronger than condition (3). Hence, condition (11) guarantees that the second order conditions are satisfied as well as that the firms undertake positive R&D levels.