The speed of technological adoption under price competition: two-tier vs. one-tier industries[*,†]

Maria Alipranti[‡] Emmanuel Petrakis[§]

April 2013

Abstract

This paper explores how vertical relations in a market affect the speed of the downstream firms' adoption of a new cost reducing technology. We shown that technology adoption may occur earlier in two-tier than in one-tier industries, independently of the structure of the upstream market. In particular, we demonstrate that, independently of the upstream market structure, both the first and the second technology adoption takes place earlier under two-tier than under one-tier industries, when the final market competition is fierce enough, the drasticity of the new technology on reducing the downstream firms' marginal cost of production is low enough and the bargaining power of upstream firm(s) in the market is low enough. Moreover, we show that the first technology adoption takes place earlier under upstream monopoly than under upstream separated firms, when the new technology is sufficiently drastic and the final market competition is fierce enough.

JEL Classification: L13, O31, L22, L41

Keywords: Technology adoption; Vertical relations; Two-part tariffs; Product Differentiation.

---

[*]This research has been co-financed by the European Union (European Social Fund .ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF)- Research Funding Program: Thalis- Athens University of Economics and Business- "New Methods in the Analysis of Market Competition: Oligopoly, Networks and Regulation".

[†]Acknowledgements: The authors wish to thank Chrysovalantou Milliou and all of the participants of the Thales Workshop, Athens University of Economics and Business, Athens, Dec. 2012 for their helpful comments and suggestions. Full Responsibility for all shortcomings is ours.

[‡]Department of Economics, University of Crete, e-mail: alipranti@econ.soc.uoc.gr.

[§]Corresponding author. Department of Economics, University of Crete, Univ. Campus at Gallos, Rethymnon 74100, Greece, Tel: +302831077409, Fax: +302831077406, e-mail: petrakis@uoc.gr.

1 Introduction

It is well established that technological innovation, as well as, the speed of the adoption of a new technology are fundamental determinants of economic development and growth, since they crucially affect the markets' performance, productivity and efficiency (Krugman, 1994). However, theoretical and empirical studies suggest that the speed of the technology adoption differs significantly not only, across nations but also, across similar firms and industries, since the firms' incentives to adopt a new technology, as well as, the timing of the adoption crucially depend on the market features, such as the market structure, the intensity of the market competition, the market's power distribution, etc. (see e.g., Klette, 1996; Klenow and Rodriguez-Clare, 1997; Griliches, 1998; Sutton, 1998; Hall and Jones, 1999; Gotz, 1999; Caselli, 2005; Klette and Kortum, 2004; Milliou and Petrakis, 2011). According to empirical observations (see e.g., Lane,1991; Charlsson and Jackobsson1994; Helper 1995) the vertical relations in a market, such as the customers/suppliers relations, affect significantly the firms' decisions to adopt a new technology with closer relations and "relational contracting" to enhance the firms' incentives to adopt a new technology.

In this paper, we investigate the firms' incentives to adopt a new cost reducing technology in vertically related markets under alternative upstream market structures (i.e., upstream separate firms market structure, upstream monopolistic market structure), as well as, the effects of the vertical relations on the firms' timing of the technology adoption. In particular, the present paper aims to answer the following three questions. First, are there any downstream firms' incentives to adopt a new cost reducing technology in vertically related markets? Second, how does the timing of the technology adoption differs between alternative industry structures (i.e, one-tier vs. two-tier industries)? Third, how do the different upstream market structures (i.e., upstream monopoly vs. upstream separate firms market structure) affect the speed of the technology adoption?

To address the above questions, we consider a vertically related industry consisted either by two upstream and two downstream firms or by an upstream monopolist and two downstream firms. The trade relations between the upstream and downstream firms in the two by two scenario are exclusive, while the trade is conducted via two-part tariffs contracts. Downstream firms are initially endowed with the same production technology when a new cost reducing technology appears in the market. If a downstream firm adopts the new technology first in the market, it achieves a competitive advantage over its rival due to the lower marginal cost of production that the adoption of the new technology implies. Instead, if a downstream firm adopts the new technology on a later date, it enjoys lower adoption costs either due to economies of learning or basic research adoption process innovation. The sequence of the movements are given as follows. At the initial date $t = 0$ downstream firms precommit to a specific technology adoption date at which the technological change will be fully implemented. At each date $t \geqslant 0$, there are two stages. In the first stage, upstream firm(s) negotiates, independently and simultaneously, with the downstream firms over the trading contract terms. In the second stage, downstream firms compete by setting their prices.

We show that, in vertically related markets, independently of the upstream market structure, downstream firms always have strong incentives to adopt the new technology. Further, in line with the one-tier industries, we find that in equilibrium there exists technological diffusion, that means that, the speed of the technology adoption alters significantly between similar firms of the same industry. Moreover, we demonstrate that the timing of the technology adoption in two-tier versus that of the one-tier industries significantly alters with regard to the intensity of the final market competition, the drasticity of the new technology on reducing the downstream firms' marginal cost of production and the bargaining power distribution in the market. In particular, we show that independently of the upstream market structure, in vertically related markets technology adoption occurs earlier than in a one-tier industries, if and only if, the bargaing power of the upstream firm(s) is low enough, the final market competition is fierce enough and the new technology is not extremely drastic. The intuition behind this result is driven by the two opposing effects that the vertical relations in a market generate, namely the output effect and the subsidization effect. In more details, under vertically related markets the wholesale prices that the downstream firms pay to their respective upstream partner(s) lead to higher prices than those obtained under one-tier industries and therefore, given the negative price-output relationship, lead to lower firms' output production. Clearly, the lower firms' output production in the vertically related markets, or in other words, the output effect of the vertical relations, tends to diminish the firms' speed of adoption of the new technology, since the cost reduction of the new technology will be applied to a lower volume of production. Further, the vertical relations in a market give rise to an additional effect named as the subsidization effect, that captures the fact that when the upstream firm(s) possess low bargaining power in market, the downstream firms are being subsidized by the upstream(s) via the fix fees.

The latter along with the fact that the subsidies are higher when the downstream firms adopt the new technology, makes the adoption of the new technology under vertically related markets more attractive and thus, it tends to increase the downstream firms' speed of the adoption. Clearly, when the bargaining power of the upstream firm(s) is low enough, the final market competition is fierce enough and the new technology is not too drastic the subsidization effect dominates the output effect and thus, the downstream firms' adoption of the new technology takes place earlier in two-tier industries than in the one-tier ones.

As far as the effects of the alternative upstream market structures on the speed of the technology adoption are being considered, we show that independently of the upstream(s) bargaining power in the market, under upstream monopolistic market structure the first technology adoption takes place earlier than under upstream separated firms market structure, if and only if, the drasticity of the new technology is sufficiently high and the final market competition is fierce enough. Interestingly enough, this finding suggests that a more competitive upstream market sector, such as separated upstream firms does not always force the speed of downstream firms' technology adoption.

There is an extensive theoretical literature that examines the firms' timing of technology adoption and the diffusion of a new technology in alternative markets (see for example, Reinganum, 1981a&b; 1983a&b; Fudenberg and Tirole, 1985; Hendricks, 1992; Riordan, 1992; Hoppe and Lehmann-Grube, 2001; Ruiz-Aliseda and Zemsky, 2006; Milliou and Petrakis 2011). In particular, Reinganum (1981a, 1983a&b) was the first to show that in a market with homogenous products and Cournot competition a new technology is diffused over the time when the firms precommit to specific dates of adoption. Similarly, Gotz (1999) demonstrates that in a market with differentiated products firms adopt the new technology at different dates, while a fiercer market competition promotes the diffusion. More recently, Milliou and Petrakis (2011), show that the timing of the adoption of a new technology could differ significantly not only, among similar firms but most importantly, among markets with alternative market features (i.e., mode of competition, the degree of product substitutability). In more details, they demonstrate that technology adoption can occur earlier in a market with Cournot competition than in a market with Betrand competition, while it can also occurs earlier in markets where the products are not close substitutes. However, to the best of our knowledge, all of the existed theoretical research and analysis over the firms' timing of adoption and the diffusion of a new technology has been restricted in one-tier industries. Thus, the present paper extends the existed literature by examining the firms' timing of adoption in vertically related markets, under alternative upstream market structures, in order to analyze how the vertical relations, as well as, the alternative upstream markets structures could affect not only, the firms' incentives to adopt a new technology but also, the speed of the firms' adoption of the new technology comparing to that of the one-tier industries.

Further, our paper is related to the limited empirical literature that examines the effects of the vertical relations and in particular, the effects of the customers/suppliers relationships over the firms' adoption of a new technology. Dore (1983,1986) has provided some evidences that show that the increased security and trust between customers and suppliers in the Japanese market due to "relational contracting" lead to more technology investment and more rapid flow of the technology information. Lane (1991) has examined the adoption of Continuous Mining Machines (CMM) in the U.S. coal industry and found that the companies which are vertically integrated to their costumers are more likely to adopt the CMM technology. Carlsson and Jacobsson (1994) have analyzed the adoption of the Automazation Technological Systems (ATS) in the Swedish engineering industry and demonstrated that the adoption of ATS is higher when customers/suppliers relations are closer. Helper (1995) has examined the adoption of Computer Numerical Control technology (CNC) in the U.S. automotive industry and showed that the closer suppliers/customers relations enhance the adoption of CNC. Although the aforementioned literature focuses on the relationship between the technology adoption and the consumers/suppliers relations in a market, it provides some initial evidences that vertical relations and integration crucially affect the firms' decision to adopt an new technology. Thus, the present paper aims to contribute to that literature by providing a number of testable implications that could be tested empirically regarding to the role of the vertical relations (i.e., input suppliers/ manufactures relations) on the adoption of a new technology, as well as, on the speed of the adoption.

The remainder of the paper is organized as follows. In Section 2, we present our main model. In section 3, we analyze and compare the firms' technology adoption patterns in vertically related markets with upstream separated firms market structure, upstream monopolistic market structure and in one-tier industries. In Section 4, we conclude. All the proofs are relegated to the Appendix.

2 The Model

We consider a two-tier industry consisting initially by two upstream and two downstream firms denoted by U_i and D_i, respectively, with $i = 1, 2$. Upstream firms are input providers with their marginal production cost being normalized to zero. Downstream firms are final good manufactures, where one unit of input is being transformed to one unit of final good. Trade relations between U_i and D_i are exclusive and trading is conducted via two part tariffs contracts (w_i, F_i), where w_i denotes the wholesale price that D_i pays per-unit of input to U_i, while F_i is the fixed fee. Each D_i sells its' final good to the consumers facing the following demand function:

$$q_i = \frac{(\alpha - p_i) - \gamma(\alpha - p_j)}{1 - \gamma^2}, \quad i, j = 1, 2; \; i \neq j; \; 0 < \gamma \leqslant 1 \tag{1}$$

where q_i and p_i are respectively D_i's output and price. The parameter γ denotes the degree of the product substitutability. The higher is γ, the closer substitutes are the final products, or in other words, the fiercer is the final market competition (Vives, 1985).

We assume a continuous and infinite time horizon denoted by, $t \geqslant 0$. Initially, downstream firms are endowed with the same constant returns to scale production technology with their marginal production cost given by $c_i = c + w_i$, where c, $0 < c < \alpha$, denotes an exogenous constant marginal cost. At date $t = 0$, a new cost-reducing technology becomes available in the market. If D_i adopts the new technology, it decreases its marginal production cost by Δ, that is, $c_i = w_i + c - \Delta$ with, $0 < \Delta < c$. The cost that firm D_i incurs at date t for adopting the new technology, is given by $k(t)$. This cost combines both the present value of the cost of purchasing the new technology and the adjustment cost of bringing the new technology on line at date t, that is given by $k(t)e^{rt}$, where r, denotes the interest rate, $0 < r < 1$. In line with, Fudenberg and Tirole (1985) and Katz and Sharipo (1987), we assume that the cost of adopting the new technology is decreasing over the time with a decreasing rate (i.e., $(k(t)e^{rt})' > 0$ and $(k(t)e^{rt})'' > 0$). Further, we assume that immediate technology adoption is prohibited due to extremely high cost (i.e., $\lim_{t \to 0} k(t) = \infty$), while the technology adoption always occur at a finite time (i.e, $\lim_{t \to 0} k(t) = \infty$). Last, as standard in the relevant literature, we assume that no other technological improvements are available in the market.

We consider two alternative scenarios with regard to the upstream market structure named as, the upstream separate firms case (in terms of notation, ST) and the upstream monopoly case (in terms of notation, MT) where, in the latter case, the upstream market sector is being monopolized by a single firm that trades with both downstream firms separately and simultaneously. The sequence of the moves under both cases is given as follows. At date $t = 0$, each downstream firm D_i precommits on a specific adoption date, T_i, at which the technological change will be fully implemented. At each date $t \geqslant 0$, there are two distinct stages. In the first stage, the upstream firm(s) negotiates with their respective downstream partners over the trading contract terms (w_i, F_i). For sake of simplicity, we assume that the distribution of the bargaining power across the vertical chains is identical, with the bargaining power of the upstream firm(s) given by β and the bargaining power of the downstream firms given by $1-\beta$, with $0 \leqslant \beta \leqslant 1$. In the second stage, downstream firms compete by setting their prices.

In order to ensure that all the participants in the market are active under all the configurations considered the following assumption should hold throughout the paper:

Assumption 1. $\gamma < \gamma(\delta)$, where $\gamma(\delta) = [-(1+\delta) + \sqrt{8 + (1+\delta)^2}]$ with $\delta = \Delta/A$ and $A = a - c$.

where, the parameter A measures the relative size of the market, while the parameter δ denotes how drastic is the technological improvement, or, in other words, the effectiveness of the new technology on decreasing the firms' marginal production cost relatively to the market size. The higher is δ, the more effective is the technological improvement in decreasing D_i's marginal cost of production.

3 Equilibrium Analysis

3.1 The Benchmark Case: One-tier Industry

We begin our analysis by briefly presenting the benchmark case that corresponds to the case of one-tier industries where, in line with Milliou and Petrakis (2011), in a duopoly market the firms decide the date of the adoption of the new technology and then, they compete by setting their price. Thus, at date $t \geqslant 0$, each firm i chooses its price p_i, taking as given the decision over the price of the rival firm p_j, in order to maximize its per -period gross profits:

$$\underset{p_i}{Max}\ \pi_i^B(.) = (p_i - c_i)\frac{(a-p_i)-\gamma(a-p_j)}{1-\gamma^2} \tag{2}$$

The first order conditions give rise to the following reaction functions,

$$R_i^B(.) = \frac{(1-\gamma)\alpha + c_i + \gamma p_j}{2} \tag{3}$$

Thus, the per-period prices and the firm i's gross profits are given respectively by:

$$p_i^B(c_i, c_j) = \frac{(2+\gamma)(1-\gamma)a + 2c_i + \gamma c_j}{4-\gamma^2}, \quad \pi_i^B(.) = \frac{[p_i^B(c_i, c_j) - c_i]^2}{(1-\gamma^2)} \tag{4}$$

Observe here that when firm i adopts the new cost reducing technology (i.e., $c_i = c - \Delta$) both its' own price, p_i^B, and the rival's firm price, p_j^B, decrease.

At the date $t = 0$, firms precommit to their adoption time T_i^B, in order to maximize their discounted sum of profits, $\Pi_i^B(T_i^B, T_j^B)$. Without loss of generality, we assume throughout the paper that when firms adopt the new technology sequentially, then firm 1 adopts it first. The discounted sum of profits are given by:

$$\underset{T_1^B}{Max}\ \Pi_1^B(.) = \int_0^{T_1^B} \pi_0^B e^{-rt}dt\ + \int_{T_1^B}^{T_2^B} \pi_l^B e^{-rt}dt\ + \int_{T_2^B}^{\infty} \pi_b^B e^{-rt}dt - k(T_1^B) \tag{5}$$

$$\underset{T_2^B}{Max}\ \Pi_2^B(.) = \int_0^{T_1} \pi_0^B e^{-rt}dt\ + \int_{T_1^B}^{T_2} \pi_f^B e^{-rt}dt\ + \int_{T_2^B}^{\infty} \pi_b^B e^{-rt}dt - k(T_2^B) \tag{6}$$

where, $\pi_0^B = \pi^B(c, c)$ are the pre-adoption gross profits of the firms, $\pi_b^B = \pi^B(c-\Delta, c-\Delta)$ are the per-period gross profits when both firms have adopted the new technology, $\pi_l^B = \pi^B(c-\Delta, c)$ and $\pi_f^B = \pi^B(c, c-\Delta)$ are respectively, the per-period gross profits of the firm that has already adopted the new technology -the leader- and those of the firm that has not yet adopted the new technology -the follower-.[1]

From the first order conditions of (5) and (6), we obtain

$$I_1^B = -k'(T_1^B)e^{-rT_1^B} \text{ and } I_2^B = -k'(T_2^B)e^{-rT_2^B} \tag{7}$$

where, I_i^B denotes each firm's incremental benefits of the technology adoption (i.e., $I_1^B =$

[1] For the detailed presentation of the expressions please see at the Appendix A1.1

$\pi_l^B - \pi_0^B$ and $I_2^B = \pi_b^B - \pi_f^B$). Clearly, by the equation (7), the optimal adoption date, T_i^B, should equalize to the firm's incremental benefits from the technology adoption to the marginal cost of waiting. Thus, using the equation (4), the incremental benefits in the benchmark case are given by,

$$I_1^B = \frac{\delta(2-\gamma)A^2[2(1-\gamma)(2+\gamma)+\delta(2-\gamma^2)]}{(1-\gamma^2)(4-\gamma^2)^2} \tag{8}$$

$$I_2^B = \frac{\delta(2-\gamma)A^2[2(1-\gamma)(2+\gamma)+\delta(2-\gamma^2-2\gamma)]}{(1-\gamma^2)(4-\gamma^2)^2} \tag{9}$$

Notice here that, $I_i^B > 0$ always hold. That is, firms always have strong incentives to adopt the available cost reducing technology, with I_1^B (I_2^B) being U shaped (inversed U shaped, respectively) related to the degree of the final market competition, γ. Moreover, we observe that, $I_1^B > I_2^B$. That means that the first adoption is more beneficial than the second one and thus, given the assumptions over the cost of the technology adoption $k(t)$, the optimal adoption dates in the benchmark case are such that, $T_1^B < T_2^B$. Therefore, in the equilibrium there exists technological diffusion.

3.2 Vertically Related Markets

We proceed now with the analysis of our basic model where in the second stage of the repeated game at date $t \geqslant 0$, independently of the upstream market structure, each downstream firm D_i chooses its price p_i, taking as given the rival's downstream firm price p_j, in order to maximize its per period gross profits given by:

$$\underset{p_i}{Max}\ \pi_i(.) = (p_i - c_i - w_i)\frac{(\alpha - p_i) - \gamma(\alpha - p_j)}{1-\gamma^2} \tag{10}$$

The first order conditions give rise to the following reaction functions,

$$R_i^V(.) = \frac{(1-\gamma)\alpha + c_i + \gamma p_j}{2} + \frac{w_i}{2} \tag{11}$$

Comparing the reaction functions in the vertically related markets, R_i^V, with the respective ones in the benchmark case, R_i^E, in which only the right part of the eq. (11) appears, we observe that the wholesale price that the downstream firms pay to their upstream partner(s) under vertically related markets, shifts the reaction functions of the vertically related markets upwards, that in turn, given that the reaction functions when firms compete in prices are upward slopping, leads to higher prices and lower firms' output production than in those of the benchmark.

Solving the system of the reaction functions (11), the equilibrium price, output and downstream firms' profits in the second stage are given respectively by,

$$p_i^V(.) = \frac{(2+\gamma)(1-\gamma)\alpha + 2(c_i+w_i) + \gamma(c_j+w_j)}{4-\gamma^2} \quad (12)$$

$$q_i^V(.) = \frac{(2+\gamma)(1-\gamma)\alpha - (2-\gamma^2)(c_i+w_i) + \gamma(c_j+w_j)}{4-5\gamma^2+\gamma^4} \quad (13)$$

$$\pi_i^V(.) = \frac{[p_i - c_i - w_i]^2}{1-\gamma^2} \quad (14)$$

Note here that, an increase in the wholesale price, w_i, tends to increase $D_i^{'}$s price, while it tends to decrease its output production. The opposite holds when D_i adopts the new technology due to the lower marginal production cost that the new technology implies (i.e., $c_i = c - \Delta$).

In the first stage of the game at date $t \geqslant 0$, upstream(s) and downstream firms bargain over the trade contract terms. Given that the bargaining game alters significantly between the case of upstream separate firms and the case of upstream monopoly in what it follows we analyze the two cases separatively.

3.2.1 Upstream Separate Firms

In this subsection we consider the case where in the market exists two separate upstream input suppliers. In the first stage of the game at date $t \geqslant 0$, each U_i and D_i pair negotiates over the trading contract terms, (w_i, F_i), taking as given the outcome of the rival's pair simultaneously run negotiation (w_j^{ST}, F_j^{ST}), in order to maximize the generalized Nash product:

$$\underset{w_i,F_i}{Max}[\pi_{U_i} + F_i]^{\beta}[\pi_{D_i} - F_i]^{1-\beta} \quad (15)$$

where, $\pi_{U_i} = w_i q_i(w_i, w_j^{ST})$ and $\pi_{D_i} = [q_i(w_i, w_j^{ST})]^2$. Note here that, given the assumption of exclusive trade relations in the market, neither U_i nor D_i could achieve an agreement with an alternative trading partner and thus, the disagreement payoffs equal zero.

Maximizing (15) with respect to F_i, we obtain:

$$F_i = \beta\pi_{D_i} - (1-\beta)\pi_{U_i} \quad (16)$$

where, by substituting (16) into (15), we observe that the net profits of U_i and D_i are given as the shares of their joint surplus, $S = \pi_{U_i} + \pi_{D_i}$,that correspond to their respective bargaining powers (β, $1-\beta$). Thus, the generalized Nash product can be rewritten as function of each vertical chain's joint surplus, while the wholesale prices are chosen such to maximize this surplus,

$$\underset{w_i}{Max} S = [a - q_i(w_i, w_j^{ST}) - \gamma q_j(w_i, w_j^{ST})] q_i(w_i, w_j^{ST}) \tag{17}$$

From the first order conditions of (17), the equilibrium per period wholesale prices are given respectively by,

$$w^{ST}(c_i, c_j) = \frac{[a(1-\gamma)(4+2\gamma-\gamma^2) + c_j\gamma(2-\gamma^2) - c_i(4-3\gamma^2)]\gamma^2}{16 - 12\gamma^2 + \gamma^4}, \quad \begin{array}{l} c_i = c \text{ or } c_i = c - \Delta \\ c_j = c \text{ or } c_j = c - \Delta \end{array} \tag{18}$$

where, using the eq.(18), the equilibrium wholesale prices in the pre adoption periods are given by, $w_0^{ST} = w^{ST}(c, c)$, the equilibrium wholesale prices in the post adoption periods are given by, $w_b^{ST} = w^{ST}(c-\Delta, c-\Delta)$, while $w_l^{ST} = w^{ST}(c-\Delta, c)$ and $w_f^{ST} = w^{ST}(c, c-\Delta)$ denote, respectively, the equilibrium wholesale price charged on the leader and the follower firm.[2]

Observe, by the eq.(18) that the equilibrium wholesale prices are independent of the bargaining power, since they are chosen in order to maximize the joint surplus of each vertical chain, while they are inversed U-shaped related to the product substitutability degree, γ. Clearly, the closer substitutes the products are, the fiercer is the final market competition that in turn, intensifies the upstream market competition and leads upstream firms to set lower wholesale prices in order to enforce their downstream partners position. In more details, a reduction in the wholesale price tends to shift the reaction function of D_i rightwards that, given the upward slope of the reaction functions, results in lower price and higher output production for the D_i firm and lower output production for the rival firm, D_j. Further, we observe, $w_l^{ST} > w_b^{ST} > w_0^{ST} > w_f^{ST}$. That means that, the upstream firms set higher wholesale prices to the downstream firms that have adopted the new technology. This is so, since the upstream firms use the wholesale prices as an instrument in order to extract part of the higher

[2]For the detailed presentation of the expressions please see at the Appendix A1.2

per period gross profits that their downstream partners obtain, due to the reduction of their marginal production cost that the adoption of the new technology implies. Yet, we observe that the wholesale price of the leader firm in adopting, w_l^{ST}, as well as, the wholesale price in the post-adoption periods, w_b^{ST}, are increasing in Δ. That means that, the more effective is the new technology on reducing the downstream firms' marginal cost of production, the higher are the wholesale prices that the upstream firms set on their respective technological advanced partners. On the contrary, the wholesale price of the follower firm, w_l^{ST}, is decreasing in Δ. That is so, because the upstream partner of the follower firm is willing by setting a lower wholesale price, or in other words, by decreasing the per-unit input price of the follower, to keep the latter active in the final market.

Lemma 1 *In vertically related market with upstream separate firms market structure,*

i) The equilibrium wholesale prices increase when the downstream firms adopt the new technology.

ii) The equilibrium wholesale prices are independent of the bargaining power β and they are inverse U-shaped in γ.

iii) The equilibrium wholesale prices of the leader firm in adopting, as well as, those when both firms have adopted the new technology are increasing in Δ, while the opposite holds for the wholesale price of the follower firm.

Using (18) and (12), it follows that the equilibrium per period prices and downstream firms' gross profits are given respectively by,

$$p_i^{ST}(c_i, c_j) = \frac{2a(4 - 2\gamma - 3\gamma^2 + \gamma^3) - (2 - \gamma^2)[c_i(\gamma^2 - 4) - 2c_j\gamma]}{16 - 12\gamma^2 + \gamma^4}, \quad \begin{array}{l} c_i = c \text{ or } c - \Delta \\ c_j = c \text{ or } c - \Delta \end{array} \tag{19}$$

$$\pi_{Di}^{ST}(c_i, c_j) = \frac{2(1 - \beta)(2 - \gamma^2)[a(4 - 2\gamma - 3\gamma^2 + \gamma^3) - (2 - \gamma^2)\gamma c_j - (4 - 3\gamma^2)c_i]^2}{(1 - \gamma)(\gamma^4 - 12\gamma^2 + 16)^2} \tag{20}$$

where, the equilibrium prices and gross profits in the pre adoption periods are given, respectively, by, $p_0^{ST} = p^{ST}(c, c)$ and $\pi_{D_0}^{ST} = \pi_D^{ST}(c, c)$. The equilibrium prices and gross profits in the post adoption periods are given respectively by, $p_b^{ST} = p^{ST}(c - \Delta, c - \Delta)$ and $\pi_{D_b}^{ST} = \pi_D^{ST}(c - \Delta, c - \Delta)$. The equilibrium price and gross profits of the leader firm are given respectively by, $p_l^{ST} = p^{ST}\ (c-\Delta, c)$ and $\pi_{D_l}^{ST} = \pi_D^{ST}(c-\Delta, c)$, while $p_f^{ST} = p^{ST}\ (c, c-\Delta)$ and $\pi_{Df}^{ST} = \pi_D^{ST}(c-, c-\Delta)$ are respectively, the equilibrium price and gross profits of the follower firm.[3]

At the same time, the equilibrium per period upstream firms' profits and the fixed fees are given respectively by,

$$\pi_{Ui}^{ST}(c_i, c_j) = \frac{2\beta(2-\gamma^2)[a(4-2\gamma-3\gamma^2+\gamma^3)-(2-\gamma^2)\gamma c_j-(4-3\gamma^2)c_i]^2}{(1-\gamma)(\gamma^4-12\gamma^2+16)^2} \tag{21}$$

$$F_i^{ST}(c_i, c_j) = \frac{(2\beta-\gamma^2)(2-\gamma^2)[a(1-\gamma)(4+2\gamma-\gamma^2)+c_j(2\gamma-\gamma^3)-c_i(4-3\gamma^2)]^2}{(1-\gamma)(\gamma^4-12\gamma^2+16)^2} \tag{22}$$

In particular, using (21) and (22), the equilibrium upstream firms' profits and the fix fees in the pre-adoption periods are given respectively by, $\pi_{U_0}^{ST} = \pi_U^{ST}(c, c)$ and $F_0^{ST} = F^{ST}(c, c)$. The equilibrium upstream firms' profits and the fix fees in the post adoption periods given respectively by, $\pi_{U_b}^{ST} = \pi_U^{ST}(c-\Delta, c-\Delta)$ and $F_b^{ST} = F^{ST}(c-\Delta, c-\Delta)$. The equilibrium upstream firm's profits and the fix fees of the leader-follower periods are given respectively by, $\pi_{U_l}^{ST} = \pi_U^{ST}(c-\Delta, c)$ and $F_l^{ST} = F^{ST}\ (c-\Delta, c)$, $\pi_{Uf}^{ST} = \pi_U^{ST}(c-, c-\Delta)$ and $F_f^{ST} = F^{ST}$ $(c, c-\Delta)$.[4]

Observe, by the eq.(22) that, $F_i^{ST} < 0$ if, $\beta < \beta_c^{ST} = \frac{\gamma^2}{2}$ with, $\frac{\partial \beta_c^{ST}}{\partial \gamma} > 0$. That means that, when the upstream firms possess relatively low bargaining power in the market they subsidize their downstream partners by transferring part of their profits downstream via the fix fees. The intuition behind the latter is that, when the upstream firms' bargaining power is low, the power to extract the fix fee is instead reversed and thus, it is the downstream firms that are benefiting by extracting the fix rents. Further, it can be checked that $\left|F_l^{ST}\right| > \left|F_b^{ST}\right| > \left|F_0^{ST}\right| > \left|F_f^{ST}\right|$. Clearly, the fix fees (subsidy, if $\beta < \beta_c^{ST}$) when a downstream firm adopts the new technology always exceed the respective ones of the pre-adoption period. Intuitively, if $\beta > \beta_c^{ST}$, the upstream firms take advantage of their bargaining power in the market and set higher fix fees to the technological advanced downstream firms in order to extract part of the higher per period gross profits that the latter obtain. On the contrary, if $\beta < \beta_c^{ST}$, the technological

[3]For the detailed presentation of the expressions please see at the Appendix A1.2

[4]For the detailed presentation of the expressions please see at the Appendix A1.2

advanced downstream firms are extracting higher subsidies by their upstream partners, with the upstream firms' losses due to the higher subsidies to be more than compensated by the higher wholesale prices that they set to the firms that have adopted the new technology.

Further, after some manipulation we observe by the eq.(22) that, $\frac{\partial F_l^{ST}}{\partial \gamma} < 0$ (independently of γ and β), $\frac{\partial F_0^{ST}}{\partial \gamma} < 0, \frac{\partial F_b^{ST}}{\partial \gamma} < 0, \frac{\partial F_f^{ST}}{\partial \gamma} < 0$ (if γ is low enough, independently of β) and $\frac{\partial F_0^{ST}}{\partial \gamma} > 0, \frac{\partial F_b^{ST}}{\partial \gamma} > 0$,$\frac{\partial F_f^{ST}}{\partial \gamma} > 0$ (if γ is high enough and β low enough). It is noteworthy here, that when the final market competition is fierce and the upstream firms' bargaining power is low, F_0^{ST} , F_b^{ST}, F_f^{ST} are increasing in γ, or in other words, the subsidies are decreasing in γ. This is because, the upstream firms via a reduction in the subsidy are willing to outweigh the reduction in the wholesale prices that the fierce final market competition implies and its' negative effects on their profitability. Yet, $\frac{\partial F_l^{ST}}{\partial \Delta} > 0, \frac{\partial F_b^{ST}}{\partial \Delta} > 0, \frac{\partial F_f^{ST}}{\partial \Delta} < 0$ if $\beta > \beta_c^{ST}$, while the opposite holds if $\beta^{ST} < \beta_c^{ST}$. That means that, when the upstream firm(s) possess relatively high bargaining power in the market, the more effective is the new technology on reducing downstream firms' marginal production cost, the higher are the fix fees that the upstream firm(s) charge to their technological advanced downstream partners. This is so, since the upstream firms take advantage of their high bargaining power in the market and transfer upwards, via the fix fees, part of the higher downstream firms' per period gross profits. In contrast, when the upstream firms possess low bargaining power in the market, a more effective new technology leads upstream firms to increase the subsidy on their technological advanced partner(s). The losses of the higher subsidies are being more than compensated by the higher wholesale prices that upstream firms charge to their technological advanced partners. Note here that for the follower firm the inverse results hold. In particular, if $\beta > \beta_c^{ST}$, the fix fees charged on the follower firm decrease as the effectiveness of the new technology increase, while if $\beta < \beta_c^{ST}$, the subsidy that the follower firm obtain decreases. The intuition behind this result is driven by the lower profitability that the follower firm obtain when its rival has adopted the new technology.

Lemma 2 *In vertically related markets with upstream separate firms market structure, the equilibrium fix fees exceed zero if,* $\beta > \beta_c^{ST}$*, while the opposite holds if,* $\beta < \beta_c^{ST}$*.*

At date $t = 0$, the downstream firms choose their adoption date T_i^{ST}, in order to maximize their discounted sum of profits given as,

$$\underset{T_1^{ST}}{Max}\ \Pi_1^{ST}(.) = \int_0^{T_1^{ST}} \pi_{D_0}^{ST} e^{-rt} dt + \int_{T_1^{ST}}^{T_2^{ST}} \pi_{D_l}^{ST} e^{-rt} dt + \int_{T_2^{ST}}^{\infty} \pi_{D_b}^{ST} e^{-rt} dt - k(T_1^{ST}) \quad (23)$$

$$\underset{T_2^{ST}}{Max}\ \Pi_2^{ST}(.) = \int_0^{T_1^{ST}} \pi_{D_0}^{ST} e^{-rt} dt + \int_{T_1^{ST}}^{T_2^{ST}} \pi_{D_l}^{ST} e^{-rt} dt + \int_{T_2^{ST}}^{\infty} \pi_{D_b}^{ST} e^{-rt} dt - k(T_2^{ST}) \quad (24)$$

From the first order conditions of (23), we have that,

$$I_1^{ST} = -k(T_1^{ST}) e^{-rT_1^{ST}} \text{ and } I_2^{ST} = -k(T_2^{ST}) e^{-rT_2^{ST}}. \quad (25)$$

Therefore, given that each downstream firm chooses the date of adoption, T_i^{ST}, such that the incremental benefits from the adoption to equalize to the marginal cost of waiting (i.e, $I_1^{ST} = \pi_l^{ST} - \pi_0^{ST}$ and $I_2^{ST} = \pi_b^{ST} - \pi_f^{ST}$), the incremental benefits in the upstream separate firms case are given by,

$$I_1^{ST} = \frac{2(1-\beta)\delta A^2(3\gamma^4 - 10\gamma^2 + 8)[2(1-\gamma)(4+(2-\gamma)\gamma) + \delta(4-3\gamma^2)]}{(1-\gamma^2)(\gamma^4 - 12\gamma^2 + 16)^2} \quad (26)$$

$$I_2^{ST} = \frac{2(1-\beta)\delta A^2(2-\gamma^2)(4-3\gamma^2)[2(1-\gamma)(4+(2-\gamma)\gamma) + \delta(2-\gamma)(2-2\gamma^2-\gamma)]}{(1-\gamma^2)(\gamma^4 - 12\gamma^2 + 16)^2} \quad (27)$$

In line with the benchmark case, $I_i^{ST} > 0$ always hold. That means that in vertically related markets with separated upstream market structure the downstream firms always have strong incentives to adopt the available cost reducing technology. Moreover, the first adoption is more beneficial than the second one (i.e., $I_1^{ST} > I_2^{ST}$) and thus, the equilibrium is characterized by technological diffusion, (i.e., $T_1^{ST} < T_2^{ST}$).

Further, comparing the firms' incremental benefits in the vertically related market with upstream separated firms market structure with the respective ones in the benchmark case, we observe that they can be higher or lower than those of the benchmark, depending on the bargaining power, β, the degree of the final market competition, γ, and the drasticity of the new technology, δ.

Insert Figures 1a and 1b

In particular, comparing the firms' incremental benefits under the vertically separate firms related market, given in (26) and (27), with the respective ones of the benchmark case, given in (8), we observe that, regarding the first technology adoption, in the equilibrium there exists $\hat{\beta}_1^{ST} \equiv \frac{\gamma^3[128-8(2+\delta)(\gamma^5+4\gamma-4\gamma^3)+(2+\delta)\gamma^7+\gamma^2(88\gamma^2-192-10\gamma^4)]}{2(\gamma^2-4)^2(3\gamma^2-4)[2(3\gamma^2+2\gamma-\gamma^3-4)+\delta(3\gamma^2-4)]}$, with $\hat{\beta}_1^{ST} < \beta_c^{ST}$, such that iff $\beta < \hat{\beta}_1^{ST}$ then, $I_1^{ST} > I_1^B$ and thus, $T_1^{ST} < T_1^B$ while, the opposite holds iff $\beta^{ST} > \hat{\beta}_1^{ST}$. Further, regarding the second adoption, we demonstrate that in the equilibrium there exists $\hat{\beta}_2^{ST} \equiv \frac{\gamma^3[8(2+\delta)(\gamma^5+4\gamma-4\gamma^3)-(2+\delta)\gamma^7+(1+\delta)(10\gamma^6+192\gamma^2-128-88\gamma^4)]}{2(\gamma^2-4)^2(3\gamma^2-4)[(2+\delta)(4-3\gamma^2)+2(1+\delta)(\gamma^3-2\gamma)}$, with $\hat{\beta}_2^{ST} < \beta_c^{ST}$, such that iff $\beta < \hat{\beta}_2^{ST}$ then, $I_2^{ST} > I_2^B$ and thus, $T_2^{ST} < T_2^B$ while, the opposite holds iff $\beta > \hat{\beta}_2^{ST}$. Notice here that if $\beta < \hat{\beta}_1^{ST}$ both $I_1^{ST} > I_1^B$ and $I_2^{ST} > I_2^B$ hold and thus, $T_1^{ST} < T_1^B$ and $T_2^{ST} < T_2^B$. Put it in other words, we show that under vertically related markets with separate upstream market structure the first and second technology adoption take place earlier than under one-tier industries, when the upstream firms possess sufficiently low bargaining power in the market, the final market competition is fierce enough and the new cost reducing technology is not too drastic. The intuition behind this result is based on the two opposing effects that the vertical relations generate in the market, named as the output effect and the subsidization effect. In more details, according to the discussion over the reaction functions in the vertically related markets and the benchmark case, we have that under two-tier industries the wholesale prices that upstream firms set to their downstream partners lead to higher prices and lower output production than the respective ones obtained under the one-tier industries. That in turn, tends to postpone the adoption of the new technology by the downstream firms, since the cost reduction of the new technology is applied to a lower volume of production. On the other hand, according to Lemma 2, when the upstream firms possess low bargaining power in the market, they subsidize their downstream partners via the fix fees, with the subsidy to increase when the downstream firms adopt the new technology. The latter reinforces the downstream firms' incentives to adopt the new technology and tends to enhance the speed of the adoption. Clearly, when the final market competition is fierce enough and the new technology is not too drastic, the output effect becomes less stronger, given that according to Lemma 1, the wholesale prices that downstream firms pay when they adopt the new technology are decreasing in γ, while, they are increasing in Δ (or else, in δ). Thus, when the upstream firms possess relatively low bargaining power in the market, the final market competition is fierce enough and the new technology is not too drastic, the subsidization effect dominates the output effect and therefore, downstream firms adopt earlier the available cost reducing technology in the vertically related market with separate upstream firms than in one-tier industries.

Proposition 1 *Vertically related markets with upstream separate firms market structure lead to earlier first and second technological adoption than one-tier industries, if and only if, the final market competition is fierce enough, the upstream firms' bargaining power is low enough and the new technology is not too drastic.*

3.3 Upstream Monopoly

In this subsection we extend our analysis considering the case of vertically related markets with monopolistic upstream market structure. In the first stage of the game, at date $t \geqslant 0$, the upstream monopolist U negotiates with each downstream firm D_i over the contract terms (w_i, F_i) taking as given the outcome of the simultaneous run negotiation with D_j (w_j^{MT}, F_j^{MT}), in order to maximize the generalized Nash product:

$$\underset{w_i, F_i}{Max}[\pi_U + F_i + F_i^{MT} - d(w_j^{MT}, F_j^{MT})]^{\beta}[\pi_{D_i} - F_i]^{1-\beta} \tag{28}$$

Note here that, the profits of the upstream monopolist are now given by the sum of its sales on both downstream firms, that is, $\pi_U = w_i q_i(w_i, w_j^{MT}) + w_j^{MT} q_j(w_i, w_j^{MT})$ while, each downstream firm's profits are given by, $\pi_{D_i} = [q_i(w_i, w_j^{MT})]^2$. Note also that, in contrast to the upstream separate firms case, under monopolistic upstream market structure the disagreement payoff is no longer null, since the upstream monopolist has an "outside option" if an agreement between a (U, D_i) pair is not reached. Thus, the upstream monopolist faces a disagreement payoff given by,

$$d(w_j^{MT}, F_i^{MT}) = w_j^{MT} q_j^{MON} + F_j^{MT} \tag{29}$$

where, $q_j^{MON} = \frac{a-c-w_j^{MT}}{2}$ is the output produced by the monopolistic downstream firm D_j in case of disagreement between the (U, D_i) pair. In more details, if an agreement between U and D_i can not be reached, the upstream monopolist is expected to obtain the revenues by the input sales on the remaining downstream firm D_j (i.e, $w_j^{MT} q_j^{MON}$) plus the fixed fee, F_j^{MT}. That means that, a breakdown in the (U, D_i) pair, does not give rise to new negotiations over the contract terms of the remaining (U, D_j) pair.

Maximizing (28) with respect to F_i, we have that,

$$F_i = \beta \pi_{D_i} - (1-\beta)[\pi_U - w_j^{MT} q_j^{MON}] \tag{30}$$

Substituting (30) into (28), we obtain that the net profits of the upstream monopolist, above its disagreement payoff, and the net profits of each downstream firm, D_i, are proportional to their joint surplus, $S^M = \pi_U + \pi_{D_i} - w_j^{MT} q_j^{MON}$, with the coefficients of proportionality to be given by their bargaining powers β and $1-\beta$, respectively. Thus, the wholesale prices w_i are chosen in order to maximize this surplus:

$$\underset{w_i}{Max} S^M = [a - q_i(w_i, w_j^{MT}) - \gamma q_j(w_i, w_j^{MT})] q_i(w_i, w_j^{MT}) + w_j^{MT}[q_j(w_i, w_j^{MT}) - q_j^{MON}] \quad (31)$$

From the first order conditions of (31), the equilibrium per period wholesale prices are given respectively by,

$$w^{MT}(c_i) = \frac{(a - c_i)\gamma^2}{4},\ c_i = c \text{ or } c_i = c - \Delta \quad (32)$$

where, using the eq. (32), the equilibrium wholesale prices in the pre adoption periods, as well as, the equilibrium wholesale price of the follower firm are given by, $w_0^{MT} = w_f^{MT} = w^{MT}(c)$, while the equilibrium wholesale prices in the post adoption periods and the equilibrium wholesale price of the leader firm are given by, $w_b^{MT} = w_l^{MT} = w^{MT}(c - \Delta)$.

Further, by the eq. (32), we observe that the equilibrium per period wholesale prices are independent of the bargaining power, β, while they are increasing in the product substitutability degree, γ. Clearly, contrary to the separate upstream firms case where the wholesale prices are inverse U- shaped related to the degree of final market competition, in the upstream monopolist case the wholesale prices are always increasing in γ due to the lack of upstream market competition. In addition, one can easily check that $w_l^{MT} = w_b^{MT} > w_0^{MT} = w_f^{MT}$. This is so, since the upstream monopolist, by setting a higher wholesale price to the downstream firms that have adopted the new technology, is willing to extract part of the higher per period gross profits that the downstream technological advanced firms obtain due to the reduction of their marginal production cost. Yet, it is easily observable that the equilibrium wholesale price charged on the leader firm in adopting, w_l^{MT}, as well as, those in the post-adoption periods, w_b^{MT}, are increasing in Δ, while the wholesale price of the follower, w_f^{MT}, is independent of Δ. Intuitively, in line with the upstream separate firms case, the more effective is the new technology on reducing the downstream firms' marginal cost of production, the higher are the wholesale prices that the upstream monopolist sets on the downstream technological advanced firms in order to extract part of the higher downstream firms' profits that a more effective technology adoption implies. Note also that, in contrast to the separate upstream firms case where the wholesale price of the follower firm is decreasing in Δ, in the upstream monopolist case the wholesale price of the follower firm is independent of Δ, since the upstream sells to both downstream firms and thus, do not have incentives to decrease the wholesale price of the follower firm in order to enforce the latter's position in the final market. Last but not least, comparing the per period equilibrium wholesale prices charged under the upstream monopolist case with the respective ones of the upstream separate firms case, we have that $w^{MT} > w^{ST}$ always hold. That means that, the lack of upstream market competition in the upstream monopolistic case leads to higher per unit of input prices.

Lemma 3 *In vertically related market with upstream monopolistic market structure,*

i) The equilibrium wholesale prices are independent of β and increasing in γ.

ii) The equilibrium wholesale price of the leader firm in adopting, as well as, those when both downstream firms have adopted the new technology, are increasing in Δ while, the respective one of the follower is independent of Δ.

iii) The equilibrium wholesale prices in the upstream monopolist case always exceed those of the upstream separate firms case.

Using (32) and (12), it follows that the equilibrium per-period prices and downstream firms' gross profits are given respectively,

$$p^{MT}(c_i, c_j) = \frac{a(2-\gamma) + 2c_i + \gamma c_j}{4}, \quad \begin{array}{l} c_i = c \text{ or } c_i = c - \Delta \\ c_j = c \text{ or } c_j = c - \Delta \end{array} \tag{33}$$

$$\pi_{Di}^{MT}(c_i, c_j) = \frac{(1-\beta)[8(a-c_i)((a-c_i)-(a-c_j)\gamma) + (3\gamma^4 - \gamma^6)(a-c_j)^2 - J(.)]}{32(1-\gamma)} \tag{34}$$

where $J(.) = 2\gamma^2[(a-c_i)^2 - (2a-1)c_i + (2a-c_j)c_j]$.

In particular, the equilibrium prices and downstream firms' gross profits in the pre adoption periods are given respectively by, $p_0^{MT} = p^{MT}(c, c)$ and $\pi_{D_0}^{MT} = \pi_D^{MT}(c, c)$. The equilibrium prices and downstream firms' gross profits in the post adoption periods are given respectively by, $p_b^{MT} = p^{MT}(c - \Delta, c - \Delta)$ and $\pi_{D_b}^{MT} = \pi_D^{MT}(c - \Delta, c - \Delta)$. The equilibrium price and gross profits of the leader firm are given, respectively, $p_l^{MT} = p^{MT}\ (c-\Delta, c)$ and $\pi_{D_l}^{MT} = \pi_D^{MT}(c-\Delta, c)$, while $p_f^{MT} = p^{MT}\ (c, c-\Delta)$ and $\pi_{Df}^{MT} = \pi_D^{MT}(c-, c-\Delta)$ are, respectively, the equilibrium price and gross profits of the follower firm.[5]

At the same time, the equilibrium per period fix fees and the upstream monopolist's profits are given respectively by,

$$F^{MT}(c_i, c_j) = \frac{(1-\beta)\gamma^2[4(a-c_i)[(a-c_j)\gamma-(a-c_i)]+2\beta[\Theta+\Phi]}{32(1-\gamma)^2} \tag{35}$$

$$\pi_U^{MT}(c_i, c_j) = \frac{[2\beta(4-\gamma^2)-(1-\beta)(3\gamma^4-\gamma^6)][2a^2+c_i^2+c_j^2-2a(c_i+c_j)]+\Xi}{32(1-\gamma^2)} \tag{36}$$

where, $\Theta = a(2-\gamma-\gamma^2)+\gamma c_j+(\gamma^2-2)c_i]$ and $\Phi = (\gamma^4-\gamma^2)(a-c_j)^2+2c_i(2a-c_i)\gamma^2+2c_j(2a-c_j)\gamma^2$ and $\Xi = 4\gamma(\gamma^2-4\beta)(a-c_i)(a-c_j)$

Note that, the equilibrium fix fees and the upstream monopolist's profits in the pre-adoption periods are given respectively by, $F_0^{MT} = F^{MT}(c,c)$ and $\pi_{U_0}^{MT} = \pi_U^{MT}(c,c)$. The equilibrium fix fees and the upstream monopolist's profits in the post adoption periods given respectively by, $F_b^{MT} = F^{MT}(c-\Delta, c-\Delta)$ and $\pi_{U_b}^{MT} = \pi_U^{MT}(c-\Delta, c-\Delta)$. The equilibrium upstream monopolist's profits in the leader-follower periods are given by, $\pi_U^{MT} = \pi_U^{MT}(c-\Delta, c)$, while the equilibrium fix fees of the leader and the follower firm are given respectively by, $F_l^{MT} = F^{MT}$ $(c-\Delta, c)$ and $F_f^{MT} = F^{MT}\ (c, c-\Delta)$.[6]

Further, by the eq. (35), we observe that $F_i^{MT} < 0$ if $\beta < \beta_c^{MT}$ where, $\beta_c^{MT} \equiv \frac{\gamma^2[4a-c+\Delta((a-c)\gamma-1)+(a-c)(\gamma^4-\gamma^2)-2\Delta\gamma^2(2(a-c)+2\Delta)}{8(a-c+\Delta)[(a-c)\gamma-(a-c+\Delta)]+(a-c)^2\gamma^2[2-3\gamma^2-\gamma^4]+4\Delta\gamma^2[2(a-c)+\Delta]}$. Clearly, in line with the upstream separate firms case, when the upstream bargaining power in the market is low enough, the fix fees turn to be negative. That means that the upstream monopolist subsidizes its downstream partners via the fix fees, with the losses of the subsidization to be covered by its input sells. In addition, using the eq. (35), we observe that, $\left|F_l^{MT}\right| > \left|F_b^{MT}\right| > \left|F_f^{MT}\right| > \left|F_0^{MT}\right|$, that implies that the fix fees (subsidies, respectively) are higher when a downstream firm adopts the new technology. Intuitively, when the upstream bargaining power is high enough (i.e., $\beta > \beta_c^{MT}$), the upstream sets higher fix fees to the downstream firms that have adopted the new technology in order to extract part of their higher per period gross profits.

[5] For the detailed presentation of the expressions please see at the Appendix A1.3

[6] For the detailed presentation of the expressions please see at the Appendix A1.3

In contrast, when the upstream bargaining power is low (i.e., $\beta < \beta_c^{MT}$), the downstream firms that have adopted the new technology are being benefiting by the higher subsidies, given that if $\beta < \beta_c^{MT}$ the power to extract the fix fees is on the downstream firms. Note also here that the losses of the higher subsidies are being more than outweighed by the higher wholesale prices that the upstream monopolist sets on the technological advanced downstream partners.

Moreover, using the eq. (35), we observe that the equilibrium per period fix fees are negatively related to the degree of the final market competition, γ, (i.e., $\frac{\partial F_l^{MT}}{\partial \gamma} < 0$,$\frac{\partial F_0^{MT}}{\partial \gamma} < 0$, $\frac{\partial F_b^{MT}}{\partial \gamma} < 0$, $\frac{\partial F_f^{MT}}{\partial \gamma} < 0$). Note here, that for $\beta < \beta_c^{MT}$, the latter result means that a fiercer final market competition forces the upstream monopolist to offer higher subsidies to its downstream partners. Yet, using the eq. (35) and after some manipulations we obtain that,$\frac{\partial F_b^{MT}}{\partial \Delta} > 0$ if $\beta > \beta_{bc}^{MT} \equiv \frac{\gamma^2(2-\gamma+\gamma^2)}{4-2\gamma-\gamma^3+\gamma^4}$ ($\frac{\partial F_b^{MT}}{\partial \Delta} < 0$ if $\beta < \beta_{bc}^{MT}$, respectively), $\frac{\partial F_l^{MT}}{\partial \Delta} > 0$ if $\beta > \beta_c^{MT}$ ($\frac{\partial F_l^{MT}}{\partial \Delta} < 0$ if $\beta < \beta_c^{MT}$, respectively) and $\frac{\partial F_f^{MT}}{\partial \Delta} < 0$ if $\beta > \beta_{fc}^{MT} \equiv \frac{\gamma^2[2(a-c)-\gamma(a-c+\Delta)(3-\gamma^2)]}{4(a-c)-\gamma(a-c+\Delta)(\gamma^4-2-3\gamma^2)}$($\frac{\partial F_f^{MT}}{\partial \Delta} > 0$, $\beta < \beta_{fc}^{MT}$, respectively). In other words, when the upstream monopolist's bargaining power is high, the more effective the new technology is, the higher are the fix fees that the upstream sets to the downstream firms that have adopt the new technology, while the opposite holds when its bargaining power is low. The result is reversed for the follower firm, since the upstream is willing to keep the follower active in the market. Last but not least, comparing the fix fees under the upstream separate firms case and the upstream monopolist case, we obtain that the fix fees are higher under the former case (i.e., $F^{MT} < F^{ST}$). Notice here, that when the upstream(s) bargaining power in the market is low, the fix fees turn to be negative and thus, the above result is reversed, or in other words, the subsidies under the upstream monopolist case are higher than the respective ones under upstream separate firms case.

Lemma 4 *In vertically related markets with upstream monopolistic market structure,*

i) The equilibrium fix fees exceed zero if, $\beta > \beta_c^{MT}$ while, the opposite holds if, $\beta < \beta_c^{MT}$.

ii) The equilibrium fix fees (subsidies, respectively) under the upstream monopolistic market structure are lower (higher, respectively) than those under the upstream separate firms market structure.

At date $t = 0$, the downstream firms decide their adoption date T_i^{MT}, in order to maximize their discounted sum of profits given by,

$$\underset{T_1^{MT}}{Max}\ \Pi_1^{MT}(.) = \int_0^{T_1^{MT}} \pi_{D_0}^{MT} e^{-rt}dt + \int_{T_1^{MT}}^{T_2^{MT}} \pi_{D_l}^{MT} e^{-rt}dt + \int_{T_2^{MT}}^{\infty} \pi_{D_b}^{MT} e^{-rt}dt - k(T_1^{MT}) \quad (37)$$

$$\underset{T_2^{MT}}{Max}\ \Pi_2^{MT}(.) = \int_0^{T_1^{MT}} \pi_{D_0}^{MT} e^{-rt}dt + \int_{T_1^{MT}}^{T_2^{MT}} \pi_{D_l}^{MT} e^{-rt}dt + \int_{T_2^{MT}}^{\infty} \pi_{D_b}^{MT} e^{-rt}dt - k(T_2^{MT}) \quad (38)$$

Taking the first order conditions of (37), we have that,

$$I_1^{MT} = -k(T_1^{MT})e^{-rT_1^{MT}} \text{ and } I_2^{MT} = -k(T_2^{MT})e^{-rT_2^{MT}} \quad (39)$$

where, given that each downstream firm chooses the date of adoption, T_i^{MT}, such that the incremental benefits from the adoption to equalize to the marginal cost of waiting (i.e, $I_1^{MT} = \pi_{D_l}^{MT} - \pi_{D_0}^{MT}$ and $I_2^{MT} = \pi_{D_b}^{MT} - \pi_{Df}^{MT}$), the incremental benefits in the upstream monopolist case are given by,

$$I_1^{MT} = \frac{(1-\beta)\delta A^2[\delta(2-\gamma^2) + 2(2-\gamma-\gamma^2)]}{8(1-\gamma^2)} \quad (40)$$

$$I_2^{MT} = \frac{(1-\beta)\delta A^2[\delta(2-2\gamma-\gamma^2) + 2(2-\gamma-\gamma^2)]}{8(1-\gamma^2)} \quad (41)$$

In line with the upstream separate firms case and the benchmark case, we observe that in vertically related markets with upstream monopolistic market structure, the downstream firms always have strong incentives to adopt the new cost reducing technology (i.e., $I_i^{MT} > 0$). Further, the equilibrium is characterized by technological diffusion, since the first adoption is more beneficial than the second one, that is, $I_1^{MT} > I_2^{MT}$ and thus, $T_1^{MT} < T_2^{MT}$.

Comparing now the incremental benefits in the upstream monopolist case, given in (40) and (41), with the respective ones in the benchmark case, given in (8), we obtain that in the equilibrium there exist, $\hat{\beta}^{MT} \equiv \frac{\gamma^4}{(\gamma^2-4)^2}$ with $\hat{\beta}^{MT} < \beta_c^{MT}$such that if, $\beta < \hat{\beta}^{MT}$ then, both $I_1^{MT} > I_1^B$ and $I_2^{MT} > I_2^B$ and thus, $T_1^{MT} < T_1^B$ and $T_2^{MT} < T_2^B$, while the inverse relation holds if, $\beta > \hat{\beta}^{MT}$. Thus, taking into account the limitations that the Assumption 1 implies over the degree of the final market competition, γ, and the drasticity of the new technology, δ, we observe that the vertically related markets with monopolistic upstream market structure lead to earlier first and second technological adoption than the one-tier industries, when the bargaining power of the upstream monopolist is low enough, the final market competition is fierce enough and the new technology is not extremely drastic. Intuitively, in line with the upstream separate firms case, when the upstream monopolist possesses low bargaining power in the market, the subsidization effect dominates the output effect and thus, the downstream firms' in the vertically related market adopt earlier the new cost reducing technology than in the one-tier industries technology.

Insert Figure 3

Proposition 2 *Vertically related markets with upstream monopolistic market structure lead to earlier first and second technological adoption than one-tier industries, if and only if, the bargaining power of the upstream monopolist is low enough, the final market competition is fierce enough and the new technology is not too drastic.*

Further, comparing the downstream firms' incremental benefits under the upstream monopolist case with the respective ones under the upstream separate firms case, we obtain that, independently of the upstream firms' bargaining power, the first technology adoption takes place earlier under the former case, if and only if, the new technology is sufficiently drastic and the final market competition is fierce enough. In particular, we show that in the equilibrium there exists $\delta^c(\gamma) \equiv \frac{2[64(1-\gamma)+80(\gamma^3-\gamma^2)+24\gamma^4-26\gamma^5+\gamma^6+\gamma^7]}{\gamma(64-80\gamma^2+26\gamma^4+\gamma^6)}$ with $\frac{\partial\delta}{\partial\gamma} < 0$, such that if $\delta > \delta^c(\gamma)$ then, $I_1^{ST} < I_1^{MT}$ and thus, $T_1^{ST} > T_1^{MT}$, while the opposite holds if $\delta < \delta^c(\gamma)$. In addition, we observe that the second technology adoption always takes place latter under the upstream monopolistic market structure than under the upstream separated market structure since, $I_2^{MT} < I_2^{ST}$ and thus, $T_2^{MT} > T_2^{ST}$. The intuition behind these result is driven by the relevant dominance of the output effect and the effect of the fix fees (subsidies, for low upstream (s) bargaining power, respectively). In more details, according to Lemma 3, the wholesale prices that downstream firms pay under the upstream monopolist case always exceed those of the upstream separate firms case. Therefore, the higher per unit input price that downstream firms face under the former case lead to lower downstream firms' output production. The latter tends to deforce the downstream firms' speed of technology adoption under the upstream monopolist case since, the new technology will be applied to a lower volume of production. On the contrary, according to Lemma 4, the fix fees under the upstream monopolist case (subsidies, if the upstream(s) bargaining power is low) are lower (higher, respectively) than those of the upstream separate firms case, that tends to enforce the speed of the technology adoption under the upstream monopolist case. Clearly, regarding the first adoption, the effect of the fix fees dominates the output effect and leads the downstream firms to adopt earlier the new technology under upstream monopolist market structure. In contrast, regarding the second technology adoption, we have that the reduction in the output production of the follower firm due to the higher per unit of input price that the follower firm pays when the market is monopolized by a single upstream firm, can not be compensated by the lower fix fees (higher subsidization, respectively) that he obtains under the upstream monopolistic market structure and thus, the second technology adoption always takes place earlier under upstream separate firms market structure.

Proposition 3 *i) In vertically related markets with upstream monopolistic market structure the first technology adoption takes place earlier than under upstream separate firms market structure, if and only if, the final market competition is fierce enough and the new technology is drastic enough.*

ii) In vertically related markets with upstream monopolistic market structure the second technology adoption takes place latter than under upstream separate firms market structure.

3.4 Extensions-Discussion

-Downstream quantities competition[7]: In our basic model, we have assumed that downstream firms in the final market compete in prices. Here, we briefly discuss how the main results of our model would change if the downstream firms compete by setting their quantities, where using (1) the inverse demand function for the final good that each D_i firm faces is given by,

$$p_i = a - q_i - \gamma q_j, \quad i, j = 1, 2;\ i \neq j;\ 0 < \gamma \leqslant 1 \tag{42}$$

Using the above inverse demand function and keeping all the other modeling specifications fixed, we reconfirmed that in vertically related markets with upstream separated market structure the downstream firms' technology adoption takes place earlier than in one -tier industries, when the upstream firms' bargaining power in the market is low enough, the final market competition is fierce enough and the new technology is not extremely drastic. We should note here

[7]For the detailed analysis please see at the Appendix C.

that under Cournot final market competition, independently of the upstream market structure, the wholesale prices in the equilibrium are always lower than the marginal cost of production of the upstream firm(s) (i.e., $w^C < 0$), while the per period fix fees always exceed zero (i.e., $F^C > 0$). That means that, under Cournot final market competition, independently of the bargaining power distribution in the market, the upstream firm(s) subsidize their downstream partners via the wholesale prices. The intuition behind this result is as follows. In vertically related markets with upstream separate market structure where the downstream firms compete in quantities, each upstream firm is willing to make its downstream partner more aggressive in the final market competition by diminishing the per-unit of input price. Clearly, the upstream partner via a lower wholesale price shifts its downstream partner's reaction function outwards and thus, given that the reaction functions under Cournot competition are downward slopping, the own downstream partner's output and gross profits increase, while the rival's downstream firm output decreases. Further, in vertically related markets with upstream monopolistic market structure where the downstream firms compete in quantities, the upstream monopolist subsidize its downstream partners via the wholesale prices, since the monopolist faces a "commitment problem". In more details, when the contracts negotiations are not fully observable, the "commitment problem" arise, since the upstream monopolist could not commit to the downstream firms that it is not going to behave opportunistically and to secretly offer a lower wholesale price to the rival downstream firm. Thus, none of the downstream firms is going to agree to a wholesale price higher than the upstream monopolist cost of production (for detailed analysis of the commitment problem see among, McAfee and Schwartz, 1995; Rey and Vergi, 2004; de Fontenay and Gans, 2005). Notice here that, under both cases, the losses of the upstream firm(s) subsidization via the wholesale prices are being more than compensated via the fix fees, since part of the increased downstream firms' gross profits due to the lower wholesale prices are being transferred upstream via the fixed fees. We should also mention here that, when downstream firms compete in quantities, the upstream firms' subsidization via the wholesale prices (i.e., $w^C < 0$), lead to higher final output production in the vertically related markets than that in the one-tier industry. The latter, named as the output effect, tends to enforce the speed of the firms' technology adoption under vertically related markets, since the new cost reducing technology will be applied in a higher production volume. On the contrary, we observe that in two-tier industries with Cournot final market competition there exists a profits sharing effect, since part of the per period profits of the downstream firms' are transferred via the fix fees to the upstream partner(s). That in turn, tends to postpone the speed of the downstream firms' technological adoption, since part of their increased per period gross profits due to the technology adoption will be transferred upwards via the fix fees. Clearly, in vertically related markets with upstream separated market structure and Cournot final market competition, when the upstream firms bargaining power is low enough, the final market competition is fierce enough and the new technology is not too drastic the output effect dominates the profits sharing effect and thus, firms' technology adoption takes place earlier than under one-tier industries. In addition, we show that in vertically related markets with upstream monopolistic market structure and Cournot final market competition the firms' adoption of the new technology always takes place latter than in one-tier industries. This is so, since when the upstream power is low in the market, that is a necessary condition in order the technology adoption to take place earlier in vertically related markets than in one-tier industries, the upstream monopolist could not cover the losses of the subsidization via the fix fees.

4 Conclusions

In the present paper we examine the downstream firms' incentives to adopt a new cost reducing technology under both upstream separated firms market structure and upstream monopolistic market structure, as well as, the effects of the vertical relations on the firms' speed of the adoption of the new technology.

We show that in vertically related markets, both under upstream separated firms and upstream monopoly market structures, downstream firms always have strong incentives to adopt the new cost reducing technology, while in the equilibrium there is technology diffusion that comes from the diminishing incremental benefits of the adoption and the decreasing adoption cost. Further, we obtain that independently of the upstream market structure, the speed of the firms' technology adoption in vertically related markets compared to that of one-tier industries alters significantly with regard to the allocation of the bargaining power in the market, the drasticity of the new technology and the intensity of the final market competition. In particular, we demonstrate that in vertically related markets the firms adopt earlier the new cost reducing technology than in one-tier industries, if and only if, the upstream bargaining power is low, the final market competition is fierce and the new technology is not too drastic. This is so, since in vertically related markets where the upstream(s) bargaining power is low enough, the downstream firms are being subsidized by their upstream partner(s) via the fix fees that in turn, given that the fix fees (subsidies, respectively) increase when the downstreams adopt the new technology, leads downstream firms to increase their speed of the technology adoption in order to get the benefit of the higher subsidies. Interestingly enough, we further show that under upstream monopolistic market structure the first adoption takes place earlier than under upstream separated firms market structure, when the new technology is sufficiently drastic and the final market competition is fierce enough. That means that a less competitive upstream market structure, captured in the upstream monopolistic market case, can encourage, under certain circumstances, the firms' speed of adoption of the new technology. The above results highlight that, the market structure (i.e.,two-tier vs. one-tier industries, upstream separated firms market structure vs. upstream monopoly market structure), as well as, the differences in the market features (i.e., the competition intensity, the allocation of the bargaining power) could alter significantly the firms' timing of technology adoption.

To the best of our knowledge the present paper is the first that provides some findings on how the vertical relations in a market affect the firms' incentives and the timing of technology adoption and more work should be done in this area. In particular, throughout the paper we have restricted our attention to the cases where firms precommit at the starting date of the game to the specific time that the technological adoption will be fully implemented. It would be interestingly enough to extend our analysis and examine how the results could alter when firms can not credibly commit to a specific time of technological adoption (i.e., preemption game). Further, it would be interesting enough to explore the firms' incentives to merge and how this can affect the speed of the adoption of a new technology. Both of these extensions are part of our future research.

Appendix

Appendix A

Appendix A.1.1 The equilibrium per period downstream profits in the benchmark case are given respectively by,

$$\pi_0^B = \pi^B(c,c) = \frac{(a-c)^2(1-\gamma)}{(\gamma-2)^2(1+\gamma)}$$

$$\pi_b^B = \pi^B(c-\Delta,c-\Delta) = \frac{(a-c-\Delta)^2(1-\gamma)}{(\gamma-2)^2(1+\gamma)}$$

$$\pi_l^B = \pi^B(c-\Delta,c) = \frac{[(a-c)(\gamma^2+\gamma-2)+\Delta(\gamma^2-2)]^2}{(\gamma^2-4)^2(1-\gamma^2)}$$

$$\pi_f^B = \pi^B(c,c-\Delta) = \frac{[(a-c)(\gamma^2+\gamma-2)+\gamma\Delta]^2}{(\gamma^2-4)^2(1-\gamma^2)}$$

Appendix A.1.2 Upstream Separate firms: The per-period equilibrium wholesale prices, prices, downstream firms' profits, fix fees and upstream firms' profits are given respectively by,

$$w_0^{ST} = \frac{(a-c)(1-\gamma)\gamma^2}{4-(2+\gamma)\gamma}$$

$$w_l^{ST} = \frac{[a(1-\gamma)(4+2\gamma-\gamma^2)+c\gamma(2-\gamma^2)-(c-\Delta)(4-3\gamma^2)]\gamma^2}{16-12\gamma^2+\gamma^4}$$

$$w_f^{ST} = \frac{[(a-c)(4-3\gamma^2)+(a-c+\Delta)(\gamma^3-2\gamma)]\gamma^2}{16-12\gamma^2+\gamma^4}$$

$$w_b^{ST} = \frac{(a-c+\Delta)(1-\gamma)\gamma^2}{4-(2+\gamma)\gamma}$$

$$p_0^{ST}(.) = \frac{2a(1-\gamma)+c(2-\gamma^2)}{4-2\gamma-\gamma^2}$$

$$p_l^{ST}(.) = \frac{2a(4-2\gamma-3\gamma^2+\gamma^3)-(2-\gamma^2)[(c-\Delta)(\gamma^2-4)-2c\gamma]}{16-12\gamma^2+\gamma^4}$$

$$p_f^{ST}(.) = \frac{2a(4-2\gamma-3\gamma^2+\gamma^3)-(2-\gamma^2)[2\Delta\gamma-c(4+2\gamma-\gamma^2)]}{16-12\gamma^2+\gamma^4}$$

$$p_b^{ST}(.) = \frac{2a(1-\gamma)+(c-\Delta)(2-\gamma^2)}{4-2\gamma-\gamma^2}$$

$$\pi_{D_0}^{ST}(.)=\frac{2(a-c)^2(1-\beta)(1-\gamma)(2-\gamma^2)}{(1+\gamma)[(2+\gamma)\gamma-4]^2}$$

$$\pi_{D_l}^{ST}(.)=\frac{2(1-\beta)(2-\gamma^2)[(4-3\gamma^2)(a-c+\Delta)-\gamma(a-c)(2-\gamma^2)]^2}{(1-\gamma)(\gamma^4-12\gamma^2+16)^2}$$

$$\pi_{D_f}^{ST}(.)=\frac{2(1-\beta)(2-\gamma^2)[(a-c)(4-3\gamma^2)+(a-c+\Delta)\gamma(\gamma^2-2)]^2}{(1-\gamma)(\gamma^4-12\gamma^2+16)^2}$$

$$\pi_{D_b}^{ST}(.)=\frac{2(a-c+\Delta)^2(1-\beta)(1-\gamma)(2-\gamma^2)}{(1-\gamma)(\gamma^4-12\gamma^2+16)^2}$$

$$F_0^{ST}(.)=\frac{(a-c)^2(1-\gamma)(2-\gamma^2)(2\beta-\gamma^2)}{(1+\gamma)[(2+\gamma)\gamma-4]^2}$$

$$F_l^{ST}(.)=\frac{(2\beta-\gamma^2)(2-\gamma^2)[a(1-\gamma)(4+2\gamma-\gamma^2)+c(2\gamma-\gamma^3)-(c-\Delta)(4-3\gamma^2)]^2}{(1-\gamma)(\gamma^4-12\gamma^2+16)^2}$$

$$F_f^{ST}(.)=\frac{(2\beta-\gamma^2)(2-\gamma^2)[a(1-\gamma)(4+2\gamma-\gamma^2)+(c-\Delta)(2\gamma-\gamma^3)-c(4-3\gamma^2)]^2}{(1-\gamma)(\gamma^4-12\gamma^2+16)^2}$$

$$F_b^{ST}(.)=\frac{(a-c+\Delta)^2(1-\gamma)(2-\gamma^2)(2\beta-\gamma^2)}{(1+\gamma)[(2+\gamma)\gamma-4]^2}$$

$$\pi_{U_0}^{ST}(.)=\frac{2\beta(a-c)^2(1-\gamma)(2-\gamma^2)}{(1+\gamma)(\gamma^2+2\gamma-4)^2}$$

$$\pi_{U_l}^{ST}(.)=\frac{2\beta(2-\gamma^2)[c\gamma(2-\gamma^2)-(c-\Delta)(4-3\gamma^2)+\alpha(4-2\gamma-3\gamma^2+\gamma^3)]^2}{(1-\gamma^2)(16-12\gamma^2+\gamma^4)^2}$$

$$\pi_{U_f}^{ST}(.)=\frac{2\beta(2-\gamma^2)[(c-\Delta)\gamma(2-\gamma^2)-c(4-3\gamma^2)+\alpha(4-2\gamma-3\gamma^2+\gamma^3)]^2}{(1-\gamma^2)(16-12\gamma^2+\gamma^4)^2}$$

$$\pi_{U_b}^{ST}(.)=\frac{2\beta(a-c+\Delta)^2(1-\gamma)(2-\gamma^2)}{(1+\gamma)(\gamma^2+2\gamma-4)^2}$$

Appendix A.1.3 Upstream Monopoly:

The per-period equilibrium wholesale prices, downstream firms' prices and profits, fix fees and upstream monopolist's profits are given respectively by,

$$w_0^{MT}=w_f^{MT}=\frac{(a-c)\gamma^2}{4}$$

$$w_b^{MT} = w_l^{MT} = \frac{(a-c+\Delta)\gamma^2}{4}$$

$$p_0^{MT}(.) = \frac{2(a+c) - \gamma(a-c)}{4}$$

$$p_l^{MT}(.) = \frac{2(a+c-\Delta) - \gamma(a-c)}{4}$$

$$p_f^{MT}(.) = \frac{2(a+c)\text{-}\gamma(a-c+\Delta)}{4}$$

$$p_b^{MT}(.) = \frac{2(a+c-\Delta) - \gamma(a-c+\Delta)}{4}$$

$$\pi_{D_0}^{MT}(.) = \frac{(a-c)^2(1-\beta)[8-(2\gamma^2+\gamma^4)(1+\gamma)]}{32(1+\gamma)}$$

$$\pi_{D_l}^{MT}(.) = \frac{(1-\beta)[\Sigma-(a-c)\gamma) - 2\gamma^2((a-c)^2+2\Delta(2(a-c)+\Delta)) + \gamma^4(a-c)^2(3-\gamma^2)]}{32(1+\gamma)}$$

where, $\Sigma = 8(a-c+\Delta)(a-c+\Delta)$

$$\pi_{Df}^{MT}(.) = \frac{(1-\beta)[V - 2\gamma^2((a-c)^2-2\Delta((a-c)-\Delta)) + \gamma^4(a-c+\Delta)^2(3-\gamma^2)]}{32(1+\gamma)}$$

where, $V = 8(a-c)[(a-c)-(a-c+\Delta)\gamma]$

$$\pi_{D_b}^{MT}(.) = \frac{(a-c+\Delta)^2(1-\beta)[8-(2\gamma^2+\gamma^4)(1+\gamma)]}{32(1+\gamma)}$$

$$F_0^{MT}(.) = \frac{(a-c)^2(2+\gamma)[\beta(4+\gamma^4-\gamma^3-2\gamma) - \gamma^2(2-\gamma+\gamma^2)]}{32(1+\gamma)}$$

$$F_l^{MT}(.) = \frac{(1-\beta)\gamma^2[Z - \gamma^2((a-c)(\gamma^2-\gamma^4) - 2\Delta(2(a-c)-\Delta)] + S]^2}{32(1+\gamma)}$$

where, $Z = 4(a-c+\Delta)[\gamma(a-c)-(a-c+\Delta)]$ and $S = 2\beta[(a-c)(2-\gamma-\gamma^2)+\Delta(2-\gamma^2)]$

$$F_f^{MT}(.) = \frac{(1-\beta)\gamma^2[N - \gamma^2(a-c)((a-c)+6\Delta)) + 3\gamma^2\Delta^2+(a-c+\Delta)\gamma^4]^2}{32(1+\gamma)}$$

where, $N = 4(a-c)[\gamma(a-c+\Delta)-(a-c)]$ and $\Omega = 2\beta[(a-c)(2-\gamma-\gamma^2)-\Delta\gamma]$

$$F_b^{MT}(.) = \frac{(a-c+\Delta)^2(2+\gamma)[\beta(4+\gamma^4-\gamma^3-2\gamma)-\gamma^2(2-\gamma+\gamma^2)]}{32(1+\gamma)}$$

$$\pi_{U_0}^{MT}(.) = \frac{(2+\gamma)(a-c)^2[(1-\gamma)\gamma^3+\beta(4-2\gamma-\gamma^3+\gamma^4)}{16(1+\gamma)}$$

$$\pi_{U_l,f}^{MT}(.) = \frac{\Lambda[2\beta(4-\gamma^2)+3(1-\beta)(\gamma^6-\gamma^4)]+4(a-c)(a-c+\Delta)(\gamma^3-4\beta\gamma)}{32(1-\gamma^2)}$$

where, $\Lambda = 2(a-c)^2+2(a-c)\Delta+\Delta^2$

$$\pi_{U_b}^{MT}(.) = \frac{(2+\gamma)(a-c+\Delta)^2[(1-\gamma)\gamma^3+\beta(4-2\gamma-\gamma^3+\gamma^4)}{(1+\gamma)(\gamma^2+2\gamma-4)^2}$$

Appendix B.

Proof of Proposition 1

We calculate the difference of the firms 1's incremental benefits in the case of the upstream separated firms, given in (26), with the respective ones of the benchmark case, given in (8): $G_1^{STB}(a,\gamma,\beta,\delta) \equiv I_1^{ST} - I_1^B$. Setting $G_1^{STB}(a,\gamma,\beta,\delta) = 0$ and solving for β, we find $\hat{\beta}_1^{ST} \equiv \frac{\gamma^3[128-8(2+\delta)(\gamma^5+4\gamma-4\gamma^3)+(2+\delta)\gamma^7+\gamma^2(88\gamma^2-192-10\gamma^4)]}{2(\gamma^2-4)^2(3\gamma^2-4)[2(3\gamma^2+2\gamma-\gamma^3-4)+\delta(3\gamma^2-4)]}$ with $\hat{\beta}_1^{ST} < \beta_c^{ST}$. It can be checked that for all γ, δ that satisfy our Assumption 1 and $\beta < \hat{\beta}_1^{ST}$, $G_1^{STB}(a,\gamma,\beta,\delta) > 0$, that is $I_1^{ST} > I_1^B$ and thus, $T_1^{ST} < T_1^B$ while, $G_1^{STB}(a,\gamma,\beta,\delta) < 0$, if $\beta > \hat{\beta}_1^{ST}$. Further, we calculate the difference of the firms 2's incremental benefits in the case of the upstream separated firms, given in (27), with the respective ones of the benchmark case, given in (8): $G_2^{STB}(a,\gamma,\beta,\delta) \equiv I_2^{ST} - I_2^B$. Setting $G_2^{STB}(a,\gamma,\beta,\delta) = 0$ and solving for β, we find $\hat{\beta}_2^{ST} \equiv \frac{\gamma^3[8(2+\delta)(\gamma^5+4\gamma-4\gamma^3)-(2+\delta)\gamma^7+(1+\delta)(10\gamma^6+192\gamma^2-128-88\gamma^4)]}{2(\gamma^2-4)^2(3\gamma^2-4)[(2+\delta)(4-3\gamma^2)+2(1+\delta)(\gamma^3-2\gamma)}$, with $\hat{\beta}_2^{ST} < \beta_c^{ST}$. It can be checked that for all γ, δ that satisfy our Assumption 1 and $\beta < \hat{\beta}_2^{ST}$, $G_2^{STB}(a,\gamma,\beta,\delta) > 0$, that is $I_2^{ST} > I_2^B$ and thus, $T_1^{ST} < T_1^B$ while, $G_2^{STB}(a,\gamma,\beta,\delta) < 0$, if $\beta > \hat{\beta}_2^{ST}$. ■

Proof of Proposition 2.

We calculate the difference of the firms 1's incremental benefits in the case of the upstream monopoly, given in (40), with the respective ones of the benchmark case, given in (8): $G_1^{MTB}(a,\gamma,\beta,\delta) \equiv I_1^{MT} - I_1^B$. Setting $G_1^{MTB}(a,\gamma,\beta,\delta) = 0$ and solving for β, we find

$\hat{\beta}^{MT} \equiv \frac{\gamma^4}{(\gamma^2-4)^2}$ with $\hat{\beta}^{MT} < \beta_c^{MT}$. It can be checked that for all γ, δ that satisfy our Assumption 1 and $\beta < \hat{\beta}^{MT}$, $G_1^{MTB}(a,\gamma,\beta,\delta) > 0$, that is $I_1^{MT} > I_1^B$ and thus, $T_1^{MT} < T_1^B$ while, $G_1^{MTB}(a,\gamma,\beta,\delta) < 0$, if $\beta > \hat{\beta}_1^{MT}$. Further, we calculate the difference of the firms 2's incremental benefits in the case of the upstream monopoly, given in (41), with the respective ones of the benchmark case, given in (8): $G_2^{MTB}(a,\gamma,\beta,\delta) \equiv I_2^{MT} - I_2^B$. Setting $G_2^{MTB}(a,\gamma,\beta,\delta) = 0$ and solving for β, we find $\hat{\beta}^{MT} \equiv \frac{\gamma^4}{(\gamma^2-4)^2}$, with $\hat{\beta}^{MT} < \beta_c^{MT}$. It can be checked that for all γ, δ that satisfy our Assumption 1 and $\beta < \hat{\beta}^{MT}$, $G_2^{MTB}(a,\gamma,\beta,\delta) > 0$, that is $I_2^{MT} > I_2^B$ and thus, $T_1^{MT} < T_1^B$ while, $G_2^{MTB}(a,\gamma,\beta,\delta) < 0$, if $\beta > \hat{\beta}^{MT}$. ■

Proof of Proposition 3.

We calculate the difference of the downstream firms 1's incremental benefits in the case of the upstream monopoly, given in (40), with the respective ones of the upstream separate firms case, given in (26): $G_1^{MS}(a,\gamma,\beta,\delta) \equiv I_1^{MT} - I_1^{ST}$. Setting $G_1^{MS}(a,\gamma,\beta,\delta) = 0$ and solving for δ, we find $\delta^c(\gamma) \equiv \frac{2[64(1-\gamma)+80(\gamma^3-\gamma^2)+24\gamma^4-26\gamma^5+\gamma^6+\gamma^7]}{\gamma(64-80\gamma^2+26\gamma^4+\gamma^6)}$ with $\frac{\partial\delta}{\partial\gamma} < 0$. It can be checked that for all γ that satisfy our Assumption 1 and $\delta > \delta^c(\gamma)$, $G_1^{MS}(a,\gamma,\beta,\delta) > 0$, that is $I_1^{MT} > I_1^{ST}$ and thus, $T_1^{MT} < T_1^{ST}$ while, $G_1^{MS}(a,\gamma,\beta,\delta) < 0$, $\delta < \delta^c(\gamma)$. Further, we calculate the difference of the firms 2's incremental benefits in the case of the upstream monopoly, given in (41), with the respective ones of the upstream separate firms case, given in (27): $G_2^{MS}(a,\gamma,\beta,\delta) \equiv I_2^{MT} - I_2^{ST}$ and after some manipulation, we show that for all γ, δ, β, $G_2^{MS}(a,\gamma,\beta,\delta) < 0$, that is $I_2^{MT} < I_2^{ST}$ and thus, $T_1^{MT} > T_1^{ST}$. ■

Appendix C Cournot Final Market Competition:

Using, (1), we have that when the downstream firms compete by setting their quantities, the inverse demand function that each D_i faces is given by,

$$p_i = a - q_i - \gamma q_j, \;\; i,j = 1,2;\; i \neq j;\; 0 < \gamma \leqslant 1$$

Benchmark case.

In the benchmark case of a one-tier industry, there exists two firms in the market that compete by choosing: First, the optimal dates of the adoption of the new technology and then, by setting their outputs. Solving the game backwards, at the second stage of the game each firm i decides its output q_i, taking as given the decision over the output of the rival firm q_j, in order to maximize its per -period gross profits:

$$\underset{q_i}{Max}\pi_i^{CB}(.) = (\alpha - q_i - \gamma q_j)q_i - c_i q_i$$

thus, each firm's per-period output and gross profits are given respectively by,

$$q_i^{CB}(.) = \frac{2(a-c_i) - \gamma(a-c_j)}{4-\gamma^2}$$

$$\pi_i^{CB}(.) = [\frac{2(a-c_i) - \gamma(a-c_j)}{(4-\gamma^2)}]^2$$

Observe here that, the downstream firm's adoption of the new technology that implies a lower marginal cost of production $(c - \Delta)$, tends to increase the own output production, q_i, while, it tends to decrease the rival's output production, q_j.

Further, at date $t = 0$, by maximizing the discounted firms' profits given as in (5) and (6) where now the per period gross profits are given respectively as follows, $\pi_0^{CB} = \pi^{CB}(c, c)$, the gross profits in the pre-adoption periods, $\pi_b^{CB} = \pi^{CB}(c - \Delta, c - \Delta)$, the per period gross profits when both firms are technologically advanced and, $\pi_l^{CB} = \pi^{CB}(c - \Delta, c)$ and $\pi_f^{CB} = \pi^{CB}(c, c - \Delta)$, the per-period gross profits of the firm that has already adopted the new technology -the leader- and those of the firm that has not yet adopted the technological change -the follower- respectively, we find that the incremental benefits of the benchmark case under Cournot market competition are given by,

$$\begin{aligned} I_1^{CB} &= \frac{4\delta A^2[(2-\gamma) + \delta]}{(4-\gamma^2)^2} \\ I_2^{CB} &= \frac{4\delta A^2[(2-\gamma) + \delta(1-\gamma)]}{(4-\gamma^2)^2} \end{aligned}$$

Note that, $I_i^{CB} > 0$, that means that under Cournot market competition firms always have strong incentives to adopt the available cost reducing technology. Further, $I_1^{CB} > I_2^{CB}$, and thus, $T_1^{CB} < T_2^{CB}$ that means that in the equilibrium the market is characterized by technological diffusion.

Vertically Related Markets

In the vertically related markets where downstream firms compete in the final market by setting their outputs, at date $t \geqslant 0$, at the second stage of the game, independently of the upstream market structure, each downstream firm D_i maximizes its' per period gross profits,

$$\underset{q_i}{Max} \pi_{D_i}(.) = (a - q_i - \gamma q_j) q_i - (c_i + w_i) q_i$$

where solving the maximization problem, we obtain that the equilibrium per periods quantities and profits in the last stage are given by,

$$q_i(c_i, c_j) = \frac{2(a - c_i) - \gamma(a - c_j) - 2w_i + \gamma w_j}{4 - \gamma^2}, \quad \begin{matrix} c_i = c \text{ or } c_i = c - \Delta \\ c_j = c \text{ or } c_j = c - \Delta \end{matrix}$$

$$\pi_{D_i}(.) = \frac{[2(a - c_i) - \gamma(a - c_j) - 2w_i + \gamma w_j]^2}{[4 - \gamma^2]^2}$$

Further, in order to ensure that all of the participants are active in the market under all the cases considered along with our basic model Assumption 1, the following assumption should also holds,

Assumption 2. $\beta \geqslant \tilde{\beta}(\gamma) = \gamma^3/(4 - 2\gamma(1 + \gamma) + \gamma^3$

The above assumption is a necessary and sufficient condition in order to ensure the existence of pure strategy pairwise proof equilibria under the case of the upstream monopolist. Non-existence of pure strategy equilibria may occur because pairwise proofness leads to negative profits for the upstream monopolist. This is so since, if for given γ, the upstream monopolist power is low enough, the upstream is being subject to opportunism and is unable to cover its losses from the input subsidization via the fixed-fees.

Upstream Separate Firms

Letting (w_j^{SC}, F_j^{SC}) denote the equilibrium outcome of the (U_j, D_j) pair's negotiations, w_i and F_i, when the downstream market competition takes place in quantities, are chosen such to maximize the generalized Nash product,

$$\underset{w_i, F_i}{Max} = [\pi_{U_i} + F_i]^{\beta} [\pi_{D_i} - F_i]^{1-\beta}$$

where, $\pi_{U_i} = w_i q_i(w_i, w_j^{SC})$ and $\pi_{D_i} = [q_i(w_i, w_j^{SC})]^2$.

Maximizing the generalized Nash product with respect to F_i, we have that,

$$F_i = \beta\pi_{D_i} - (1-\beta)\pi_{U_i}$$

Substituting the above equation into the generalized Nash product, we observe that the net profits of the U_i and D_i are given by the shares of their joint surplus, $S = \pi_{U_i} + \pi_{D_i}$, that corresponds to their respective bargaining power $(\beta, 1-\beta)$ Thus, the generalized Nash product can be rewritten as function of the vertical chain's joint surplus, while the wholesale prices, w_i, are chosen in order to maximize that surplus,

$$\underset{w_i}{Max} S = [a - q_i(w_i, w_j^{SC}) - \gamma q_j(w_i, w_j^{SC})] q_i(w_i, w_j^{SC})$$

Taking the first order conditions of the above expression, the per period equilibrium wholesale prices under Cournot final market competition are given by,

$$w^{SC}(c_i, c_j) = -\frac{\gamma^2[a(4-\gamma(2+\gamma) - (4-\gamma^2)c_i + 2c_j]}{16 - 12\gamma^2 + \gamma^4} \quad \begin{array}{l} c_i = c \text{ or } c_i = c - \Delta \\ c_j = c \text{ or } c_j = c - \Delta \end{array}$$

In particular, the equilibrium wholesale prices in the pre adoption periods are given by, $w_0^{SC} = w^{SC}(c, c)$, the equilibrium wholesale prices in the post adoption periods are given by, $w_b^{SC} = w^{SC}(c-\Delta, c-\Delta)$ while, $w_l^{SC} = w^{SC}(c-\Delta, c)$ and $w_f^{SC} = w^{SC}(c, c-\Delta)$ denote the equilibrium wholesale price charged on the leader and the follower firm, respectively. Observe here that under Cournot final market competition the per period equilibrium wholesale prices are always lower than the upstream firms' marginal cost of production. That means that, when the downstream firms compete in the final market by setting their quantities, the upstream firms subsidize their downstream partners via the wholesale prices. This is so, since each upstream firm by setting a lower wholesale price to its downstream partner is willing to make the latter more aggressive in the final market. In more details, a lower wholesale price shifts out the reaction function of the downstream firm and thus, given that the reaction functions under Cournot competition are downward slopping, the output of the rival downstream firm decrease while, the output and the per period gross profits of the own downstream firm increase. Part of these increased downstream firm's per period gross profits are transferred via the fixed fees upstream and thus, the upstream firm more than cover the losses of the downstream's subsidization. Note also, that the equilibrium wholesale prices decrease when the downstream firms adopt the new technology.

Further, the downstream firms' equilibrium per period output and gross profits under Cournot final market competition are given respectively by,

$$q_i^C(c_i, c_j) = \frac{2a(4-2\gamma-\gamma^2)+4\gamma c_j - 2c_i(4-\gamma^2)}{16-12\gamma^2+\gamma^4}, \quad \begin{array}{l} c_i = c \text{ or } c-\Delta \\ c_j = c \text{ or } c-\Delta \end{array}$$

$$\pi_{D_i}^C(c_i, c_j) = \frac{2(1-\beta)(2-\gamma^2)[a(4-2\gamma-\gamma^2)+2\gamma c_j - (4-\gamma^2)c_i]^2}{(16-12\gamma^2+\gamma^4)^2}$$

where, the equilibrium output and gross profits in the pre adoption periods are given by, $q_0^C = q^{ST}(c, c)$ and $\pi_{D_0}^C = \pi_D^C(c, c)$, respectively. The equilibrium output and gross profits in the post adoption periods are given respectively by, $q_b^C = q^C(c-\Delta, c-\Delta)$ and $\pi_{D_b}^C = \pi_D^C(c-\Delta, c-\Delta)$. The equilibrium output and gross profits of the leader firm are given, respectively, $q_l^C = q^C$ $(c-\Delta, c)$ and $\pi_{D_l}^C = \pi_D^C(c-\Delta, c)$ while $q_f^C = q^C$ $(c, c-\Delta)$ and $\pi_{Df}^C = \pi_D^C(c-, c-\Delta)$ are respectively, the equilibrium output and gross profits of the follower firm.

At the same time, the equilibrium per period upstream firms' profits and the fixed fees are given respectively by,

$$\pi_{U_i}^C(c_i, c_j) = \frac{2\beta(2-\gamma^2)[a(4-2\gamma-\gamma^2)+2\gamma c_j - (4-\gamma^2)c_i]^2}{(16-12\gamma^2+\gamma^4)^2}$$

$$F_i^C(c_i, c_j) = \frac{2[2\beta+(1-\beta)\gamma^2][a(2\gamma+\gamma^2-4)-2\gamma c_j + (4-\gamma^2)c_i]^2}{(16-12\gamma^2+\gamma^4)^2}$$

In particular, the equilibrium upstream firms' profits and the fix fees in the pre-adoption periods are given respectively by, $\pi_{U_0}^C = \pi_U^C(c, c)$ and $F_0^C = F^C(c, c)$. The equilibrium upstream firms' profits and the fix fees in the post adoption periods given respectively by, $\pi_{U_b}^C = \pi_U^C(c-\Delta, c-\Delta)$ and $F_b^C = F^C(c-\Delta, c-\Delta)$. The equilibrium upstream firm's profits and fix fees of the leader-follower periods are given respectively by, $\pi_{U_l}^C = \pi_U^C(c-\Delta, c)$ and $F_l^C = F^C$ $(c-\Delta, c)$, $\pi_{Uf}^C = \pi_U^C(c-\Delta, c-\Delta)$ and $F_f^C = F^C$ $(c, c-\Delta)$. Observe here that, in contrast to the respective case of Betrand final market, when the final market competition takes place in quantities the fix fees that the upstream firms set always exceed zero, independently of the bargaining power that upstream firms possess in the market.

Further, at date $t = 0$, by maximizing with respect to T_i the discounted downstream firms profits given as in the equation (23), where the period profits are given now by, $\pi^C_{D_0}$, $\pi^C_{D_b}$, $\pi^C_{D_l}$ and π^C_{Df}, we obtain that the incremental benefits in the upstream separate firms case when the downstream firms compete by setting their quantities are given by,

$$I_1^C = \frac{2(1-\beta)\delta A^2(\gamma^4-6\gamma^2+8)[2(4-\gamma(\gamma+2)+\delta(4-\gamma^2)]}{(\gamma^4-12\gamma^2+16)^2}$$

$$I_2^C = \frac{2(1-\beta)\delta A^2(\gamma^4-6\gamma^2+8)[2(4-\gamma(\gamma+2)+\delta(4-\gamma(\gamma+4))]}{(\gamma^4-12\gamma^2+16)^2}$$

Observe here that, under vertically related markets with upstream separate firms market structure and Cournot final market competition, the downstream firms always have strong incentives to adopt the new technology since, $I_i^C > 0$, while, at the same time, in the equilibrium there exists technological diffusion, since $I_1^C > I_2^C$, and thus, $T_1^C < T_2^C$.

Further, comparing the firms' incremental benefits under the upstream separate firms market structure with the respective ones of the benchmark case, when downstream firms compete in quantities, we show that in the equilibrium there exists $\hat{\beta}_1^C \equiv \frac{\gamma^3[128-(2+\delta)(96\gamma+80\gamma^3-16\gamma^5+\gamma^7)-4(2\gamma^4+\gamma^6)]}{(\gamma^2-4)^3(2-\gamma^2)[(2+\delta)(4-\gamma^2)-4\gamma)]}$, such that if $\beta < \hat{\beta}_1^C$ then, $I_1^C > I_1^{CB}$ and thus, $T_1^C < T_1^{CB}$, while the opposite holds if, $\beta > \hat{\beta}_1^C$. Further, regarding the second technology adoption, we demonstrate that in the equilibrium there exists $\hat{\beta}_2^{ST} \equiv \frac{\gamma^3[2(2-\gamma)(4-2\gamma-\gamma^2)][8-(4+\gamma(8-\gamma-\gamma^2)]+\delta[128-\gamma(96+(\gamma^2-2)\gamma(\gamma+4)(4-2\gamma-\gamma^2)]}{(\gamma^2-4)^3(2-\gamma^2)[(2+\delta)(4-\gamma-\gamma^2)]}$, such that if $\beta < \hat{\beta}_2^C$ then, $I_2^C > I_2^{CB}$ and thus, $T_2^C < T_2^{CB}$ while, the opposite holds if, $\beta > \hat{\beta}_2^C$. Thus, given the above results and our Assumption 2, it is clear that, two-tier industries with upstream separate firms market structure and Cournot final market competition, lead to earlier first and second adoption than one-tier industries, if and only if, the upstream firms' bargaining power is low enough, the final market competition is fierce enough and the new technology is not too drastic. The intuition behind this result, is based on the two opposing effects that vertical relations generate in the market, named as the output effect and the profits sharing effect. In more details, as we have already mentioned, in vertically related markets with upstream separate firms and Cournot final market competition the wholesale prices that upstream firms set are always below their marginal production cost, while they decrease when the downstream firms adopt the new technology. Thus, given the subsidization of the downstream firms production via the lower wholesale prices, we have that the final output production under vertically related markets with Cournot final market competition is higher than under one tier industries. The latter, named as the output effect, tends to enforce the downstream firms' speed of technology adoption in the vertically related markets with upstream separate firms markets structure and Cournot final market competition, since the new technology will be applied to a higher volume of production. On the contrary, we observe that in two-tier industries with Cournot final market competition there exists a profits sharing effect, since part of the per period profits of the downstream firms' are transferred via the fix fees to the upstream firms. That in turn, tends to postpone the speed of the downstream firms' technological adoption since, part of their increased per period gross profits due to the technology adoption will be transferred upwards via the fix fees. Clearly, when the final market competition is fierce enough, the upstream firms possess low bargaining power and the new technology is not extremely drastic the output effect dominates the profits sharing effect and thus, the first and second technology adoption take place earlier in two-tier industries than in the one-tier ones.

Upstream Monopoly

Letting $(w_j^{MC},\ F_j^{MC})$ denote the equilibrium outcome of the $(U,\ D_j)$ pair's negotiations, w_i, F_i, when the downstream market competition takes place in quantities, are chosen such to maximize the generalized Nash product,

$$\underset{w_i,F_i}{Max} = [\pi_U + F_i + F_i^{MC} - d(w_j^{MC}, F_j^{MC})]^{\beta}[\pi_{D_i} - F_i]^{1-\beta}$$

where, $\pi_U = w_i q_i(w_i, w_j^{MC}) + w_j^{MC} q_j(w_i, w_j^{MC})$ and $\pi_{D_i} = [q_i(w_i, w_j^{MC})]^2$, while the outside option is given by, $d(w_j^{MC}, F_i^{MC}) = w_j^{MC} q_j^{MON} + F_j^{MC}$ with $q_j^{MON} = \frac{a-c-w_j^{MC}}{2}$.

Maximizing the generalized Nash product with respect to F_i, we have that,

$$F_i = \beta\pi_{D_i} - (1-\beta)[\pi_U - w_j^{MC} q_j^{MON}]$$

Substituting the above equation into the generalized Nash product, we obtain that the net profits of the upstream monopolist, above its disagreement payoff, and the net profits of D_i, are proportional to their joint surplus, $S^{MC} = \pi_U + \pi_{D_i} - w_j^{MC} q_j^{MON}$, with the coefficients of proportionality to be given by their bargaining powers β and $1-\beta$, respectively. Thus, the wholesale prices w_i are chosen in order to maximize this surplus:

$$\underset{w_i}{Max} S^{MC} = [a - q_i(w_i, w_j^{MC}) - \gamma q_j(w_i, w_j^{MC})] q_i(w_i, w_j^{MC}) + w_j^{MC}[q_j(w_i, w_j^{MC}) - q_j^{MON}]$$

From the first order conditions of the above equation, we obtain that the equilibrium per period wholesale prices in the vertically related markets with upstream monopolist market structure when the final market competition takes place in quantities, are given respectively by,

$$w^{MC}(c_i) = -\frac{(a - c_i)\gamma^2}{2(2 - \gamma^2)}, c_i = c \text{ or } c_i = c - \Delta$$

in particular, the equilibrium wholesale prices in the pre adoption periods, as well as, the equilibrium wholesale price of the follower firm are given by, $w_0^{MC} = w_f^{MC} = w^{MC}(c)$, the equilibrium wholesale prices in the post adoption periods, as well as, the equilibrium wholesale price of the leader firm in adopting are given by, $w_l^{MC} = w_b^{MC} = w^{MC}(c - \Delta)$.

Observe here that, the upstream monopolist's per period equilibrium wholesale prices are always lower than the upstream's marginal cost of production. That means that, the upstream monopolist subsidizes its downstream partners via the wholesale prices. This is so, due to the so called "commitment problem" that arises when the contracts negotiations are not fully observable, since the upstream monopolist could not commit to the downstream firms that it is not going to behave opportunistically and to secretly offer a lower wholesale price to the rival downstream firm in order to make the latter more competitive in the final market. The upstream monopolist has incentives to offer a lower wholesale price, since he will extract the benefit of the higher gross profits that the favored downstream partner will obtain by transferring part of these higher profits upstream via the fix fees. Thus, given that the downstream firms are aware of the upstream monopolist's incentives to behave opportunistically, none of the them is going to agree to a wholesale price higher than the upstream monopolist cost of production (for detailed analysis of the commitment problem see among, McAfee and Schwartz, 1995; Rey and Vergi, 2004; de Fontenay and Gans, 2005). Note also, that the equilibrium wholesale prices decrease when the downstream firms adopt the new cost reducing technology.

Further, the downstream firms' equilibrium per period output and gross profits under

Cournot final market competition are given respectively by,

$$q_i^{MC}(c_i, c_j) = \frac{2(a-c_i)-(a-c_j)\gamma}{4-\gamma^2}, \quad \begin{array}{l} c_i = c \text{ or } c-\Delta \\ c_j = c \text{ or } c-\Delta \end{array}$$

$$\pi_{D_i}^{MC}(c_i, c_j) = \frac{(1-\beta)[2c_i - \gamma c_j - a(2-\gamma)]^2}{8(2-\gamma^2)^2}$$

where, the equilibrium output and gross profits in the pre adoption periods are given by, $q_0^{MC} = q^{MC}(c, c)$ and $\pi_{D_0}^{MC} = \pi_D^{MC}(c, c)$, respectively. The equilibrium output and gross profits in the post adoption periods are given respectively by, $q_b^{MC} = q^{MC}(c-\Delta, c-\Delta)$ and $\pi_{D_b}^{MC} = \pi_D^{MC}(c-\Delta, c-\Delta)$. The equilibrium output and gross profits of the leader firm are given, respectively by, $q_l^{MC} = q^{MC}$ $(c-\Delta, c)$ and $\pi_{D_l}^{MC} = \pi_D^{MC}(c-\Delta, c)$, while $q_f^{MC} = q^{MC}$ $(c, c-\Delta)$ and $\pi_{Df}^{MC} = \pi_D^{MC}(c-\Delta, c-\Delta)$ are respectively, the equilibrium output and gross profits of the follower firm.

At the same time, the equilibrium per period upstream monopolist's profits and the fixed fees are given respectively by,

$$\pi_{U_i}^{MC}(c_i, c_j) = \frac{2\beta(2-\gamma^2)[a(4-2\gamma-\gamma^2)+2\gamma c_j - (4-\gamma^2)c_i]^2}{(16-12\gamma^2+\gamma^4)^2}$$

$$F_i^C(c_i, c_j) = \frac{2[2\beta+(1-\beta)\gamma^2][2c_i - \gamma c_j - a(2-\gamma)]^2}{8(\gamma^2-2)^2}$$

In particular, the equilibrium upstream monopolist's profits and the fix fees in the pre-adoption periods are given respectively by, $\pi_{U_0}^{MC} = \pi_U^{MC}(c, c)$ and $F_0^{MC} = F^{MC}(c, c)$. The equilibrium upstream monopolist's profits and the fix fees in the post adoption periods given respectively by, $\pi_{U_b}^{MC} = \pi_U^{MC}(c-\Delta, c-\Delta)$ and $F_b^{MC} = F^{MC}(c-\Delta, c-\Delta)$. The equilibrium fix fees of the leader-follower periods are given respectively by, $F_l^{MC} = F^{MC}$ $(c-\Delta, c)$, and $F_f^{MC} = F^{MC}$ $(c, c-\Delta)$ and the equilibrium upstream monopolist's profits in the leader-follower periods are given by $\pi_U^{MC} = \pi_U^{MC}(c-\Delta, c)$. Observe here that, in contrast to the Betrand final market competition case, when the final market competition takes place in quantities the fix fees that the upstream monopolist sets always exceed zero, independently of its bargaining power in the market.

Further, at date $t = 0$, by maximizing with respect to T_i the discounted downstream firms profits given as in the equation (37) where, the period profits are given now by, $\pi_{D_0}^{MC}$, $\pi_{D_b}^{MC}$,

$\pi_{D_l}^{MC}$ and π_{Df}^{MC}, we obtain that the incremental benefits in the upstream monopolist case when the downstream firms compete by setting their quantities are given by,

$$I_1^{MC} = \frac{(1-\beta)\delta A^2[(2-\gamma)+\delta]}{2(2-\gamma^2)}$$

$$I_2^{MC} = \frac{(1-\beta)\delta A^2[(2-\gamma)+\delta(1-\gamma)]}{2(2-\gamma^2)}$$

Observe here that, in line with our basic model's results, in vertically related markets with upstream monopolistic market structure and Cournot final market competition the downstream firms always have strong incentives to adopt the new technology, since $I_i^{MC} > 0$, while, at the same time, in the equilibrium there exists technological diffusion, since $I_1^{MC} > I_2^{MC}$, and thus, $T_1^{MC} < T_2^{MC}$.

Comparing now the firms' incremental benefits under the upstream monopolistic market structure with the respective ones of the benchmark case, when the final market competition takes place in quantities, we show that in the equilibrium the firms' incremental benefits in the benchmark case always exceed those of upstream monopolist case, that is, $I_1^{MC} < I_1^{CB}$ and thus, $T_1^{MC} > T_1^{CB}$ and $I_2^{MC} < I_2^{CB}$ and thus, $T_2^{MC} > T_2^{CB}$. In other words, we demonstrate that in two-tier industries, under upstream monopolistic market structure and Cournot final market competition, the technology adoption always takes place latter than in one-tier industries. This is so, since as we have see by our analysis in order the technology adoption to take place earlier under vertically related market, the upstream's sector bargaining power in the market should be low enough. However, given our Assumption 2, in the upstream monopolistic case where downstream firms compete in quantities a low enough upstream monopolist's bargaining power in the market leads to negative profits for the upstream. In other words, when the upstream's power in the market is low enough, the upstream monopolist is unable to cover its losses from the input subsidization via the fixed-fees.

Figures

In the following figures (i.e., Figs. 1a &1b), ΔI_i, ($i = 1, 2$,respectively) denotes the geometrical locus, as function of the product substitutability degree (γ) and the drasticity of the new cost reducing technology (δ), where the firm i's incremental benefits in the separated vertically related market equal those of the benchmark case of the one tier industry (i.e, $I_i^{ST} = I_i^B$

and thus, $T_i^{ST} = T_i^B$). On the right of ΔI_i (area A) the firm i's incremental benefits in the separated vertically related market exceed those of the benchmark case (i.e, $I_i^{ST} > I_i^B$ and thus, $T_i^{ST} < T_i^B$) while, the opposite hold on the left of ΔI_i (area B) (i.e, $I_i^{ST} < I_i^B$and thus, $T_i^{ST} > T_i^B$). Last but not least, the area on the right of As.1 (area Γ) has been excluded from our analysis since it does not satisfy the basic assumption of our model.

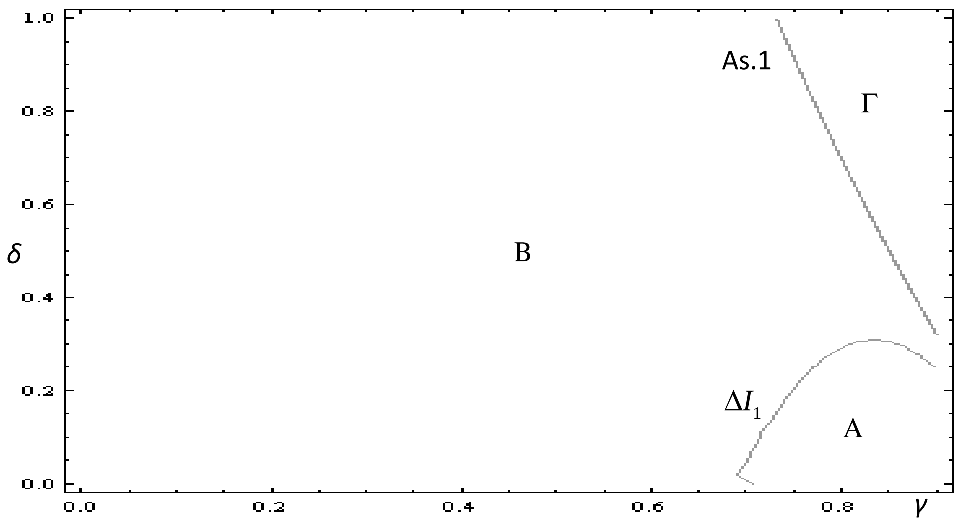

Fig.1a. The geometrical locus, ΔI_1 , where firm 1's incremental benefits obtained in the upstream separate firms case equal those of the benchmark case as function of γ and δ and with respect to basic assumption of the model, As.1. (β=0.05)

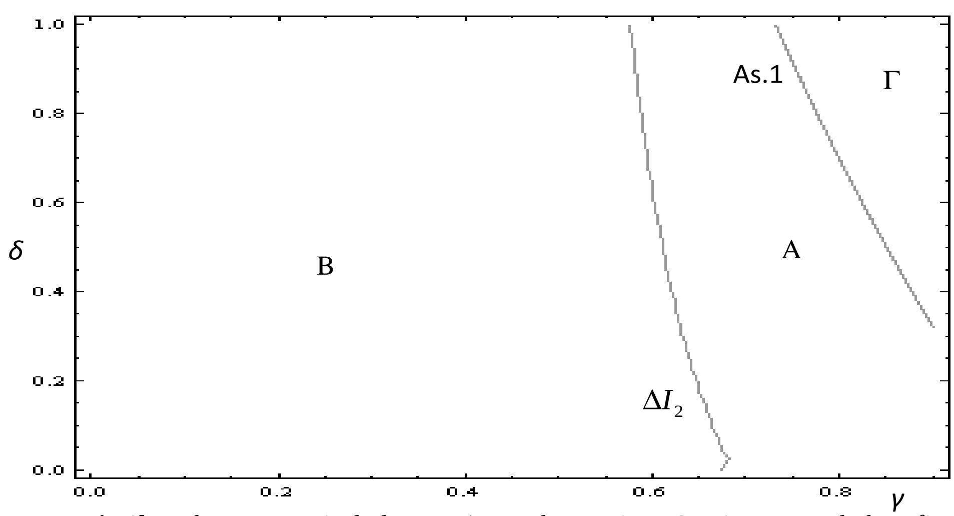

Fig.1b. The geometrical locus, ΔI_2, where Firm 2's incremental benefits obtained in the upstream separate firms case equal those of the benchmark case as function of γ and δ and with respect to basic assumption of the model, As.1.(β=0.05)

In the following figure (i.e., Fig. 3), ΔI_i, ($i = 1, 2$,respectively) denotes the geometrical locus, as function of the product substitutability degree (γ) and the drasticity of the new cost reducing technology (δ), where the firm i's incremental benefits in the monopolistic vertically related market equal those of the benchmark case of the one tier industry (i.e, $I_i^{MT} = I_i^B$ and thus, $T_i^{MT} = T_i^B$). On the right of ΔI_i (area A) the firm i's incremental benefits in the monopolistic vertically related market exceed those of the benchmark case (i.e, $I_i^{MT} > I_i^B$ and thus, $T_i^{MT} < T_i^B$) while, the opposite hold on the left of ΔI_i (area B) (i.e, $I_i^{MT} < I_i^B$and thus, $T_i^{MT} > T_i^B$). Last but not least, the area on the right of As.1 (area Γ) has been excluded from our analysis since it does not satisfy the basic assumption of our model.

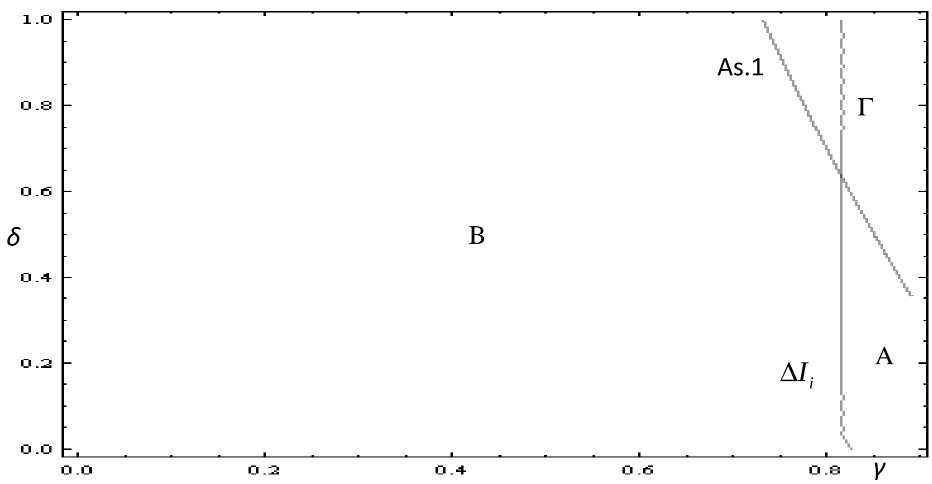

Fig.3. The geometrical locus, ΔI_i, where Firm i's incremental benefits obtained in the upstream monopolist case equal those of the benchmark case as function of γ and δ and with respect to basic assumption of the model, As.1. (β=0.04)

References

[1] Caselli, F., (2005), "Accounting for Cross-Country Income Differences", Handbook of Economic Growth, pp. 679–741.

[2] Carlsson B., and Jacobsson S., (1994), "Technological Systems and Economic Policy: The Diffusion of Factory Automation in Sweden", Research Policy, 23, pp.235-248.

[3] de Fontenay, C.C., and Gans J.S., (2005), "Vertical Integration in the Presence of Upstream Competition", Rand Journal of Economics, 36, pp. 544-572.

[4] Fudenberg, D., and Tirole, J., (1985), "Preemption and rent equalization in the adoption of new technology", Review of Economic Studies, 52, pp. 383–401.

[5] Gotz, G., (1999), "Monopolistic Competition and the Diffusion of New Technology", Rand Journal of Economics, 30, pp. 679-693.

[6] Griliches, Z., (1998), "R&D and Productivity: The Econometric Evidence", NBER Monograph series, Chicago: University of Chicago Press.

[7] Hall, R.E, and Charles I.J, (1999), "Why Do Some Countries Produce So Much More Output per Worker Than Others?", Quarterly Journal of Economics, 114, pp. 83–116.

[8] Helper, S., (1995), "Supplier Relations and Adoption of New Technology: Results of Survey Research in the U.S. Auto Industry", NBER Working Paper #5278.

[9] Hendricks, K., (1992), "Reputation in the adoption of a new technology", International Journal of Industrial Organization, 10, pp. 663–677.

[10] Hoppe, H., (2002), "The timing of new technology adoption: theoretical models and empirical evidence", The Manchester School, 70, pp. 5676.

[11] Katz, M., and Shapiro, C., (1987), "R&D Rivalry with Licensing or Imitation", American

[12] Economic Review, 77, pp. 402-420.

[13] Klenow, P.J., and Rodriguez-Clare, A., (1997), "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?", NBER Macroeconomics Annual 1997,Cambridge, MA: MIT Press, pp. 73–103.

[14] Klette, T.J., (1996), "R&D, Scope Economies, and Plant Performance", RAND Journal of Economics, 27, pp. 502–22.

[15] Krugman, P. (1994). Peddling Prosperity, New York, Norton.

[16] Lane, S., (1991), "The Determinants of Investment in New Technology", American Economic Review, 81 pp. 262–65.

[17] McAfee, P., and Schwartz, M., (1995),"The non-existence of pairwise-proof equilibrium", Economics Letters, 49, pp. 251–259.

[18] Milliou, C., and Petrakis E., (2011), "Timing of technology adoption and product market competition," International Journal of Industrial Organization, Elsevier, 29, pp. 513-523

[19] Milliou, C. and Petrakis E., (2007), "Upstream Horizontal Mergers, Vertical Contracts, and Bargaining", International Journal of Industrial Organization, 25, pp. 963-987.

[20] Riordan, M., (1992), "Regulation and preemptive technology adoption", Rand Journal of Economics, 23, pp. 334–349

[21] Rey, P., and Verge T., (2004), "Bilateral Control with Vertical Contracts", Rand Journal of Economics, 35, pp. 728-746.

[22] Reinganum, J., (1981a), "On the diffusion of new technology: a game theoretic approach", Review of Economic Studies, 48, pp. 395–405.

[23] Reinganum, J., (1981b), "Market structure and the diffusion of new technology", The Bell Journal of Economics, 12, pp. 618–624.

[24] Reinganum, J., (1983a), "Technology adoption under imperfect information", The Bell Journal of Economics, 14, pp. 57–69.

[25] Reinganum, J., (1983b), "Uncertain innovation and the persistence of monopoly", American Economic Review, 73, pp. 741–748.

[26] Ruiz-Aliseda, F., and Zemsky, P., (2006), "Adoption isnot Development: First Mover Advantages in the Diffusion of New Technology", Insead Working Paper, 2007/03/ST.

[27] Schumpeter, J., (1934), "The Theory of Economic Development", Cambridge, Mass: Harvard University Press.

[28] Sutton, J., (1998), "Technology and Market Structure: Theory and History", Cambridge, MA: MIT Press.

[29] Vives, X., (1985), "On the Efficiency of Bertrand and Cournot Equilibria with Product Differentiation", Journal of Economic Theory, 36, pp. 166-175.