DEPARTMENT OF ECONOMICS

UNIVERSITY OF CRETE

BE.NE.TeC. Working Paper Series

Working Paper: 2008-15

Do firms' owners delegate both short-run and long-run decisions to their managers in equilibrium?

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Business Economics & NEw TeChnologies Laboratory

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Do firms' owners delegate both short-run and long-run decisions to their managers in equilibrium? *

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May 2010

Abstract

This paper explores the scope of strategic delegation, in a market where firms invest in cost reducing R&D and compete in quantities. The firms' owners' have two alternative strategies: either to delegate both short-run and long-run decisions to their managers (Full Delegation) or to delegate only the short-run decisions (Partial Delegation). We find that when the initial unit cost is relatively high Universal Full Delegation emerges in equilibrium. Otherwise an asymmetric equilibrium where one firm chooses Full Delegation and the other Partial Delegation arises. These results however are sensitive to the ability of firms' owners to commit to their delegation strategies. Welfare analysis is also conducted.

JEL Classification: C20, C72, L22, O33.

Keywords: Strategic Delegation, Oligopoly, R&D Investments, Equilibrium Delegation Schemes.

*The authors wish to thank Michael Kopel and the participants at the European Association for Research in Industrial Economics - EARIE33 2006 at Amsterdam for their helpful comments and suggestions. Full responsibility for all shortcomings is ours.

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1 Introduction

It is considered a stylized fact that modern corporations are characterized by a separation of ownership and management, or in other words, delegation of decisions from owners to managers (Fama and Jensen 1983). So far, literature focuses on two kinds of delegation. The first derives from the owners' need to exploit specific competencies that certain individual managers may embody, in order to improve the efficiency of their firms under asymmetry of information and moral hazard. This kind of delegation is thoroughly examined by using principal-agent models.[1] The second is related to the acquisition of commitment ability that allows firms' managers to render credible strategies that the owners themselves are unwilling to choose. In particular, the owner of a firm may change the behavior of a rival firm in his favor, by hiring a manager whose preferences are different from his own. This sort of delegation has prevailed in the literature as "strategic delegation" and was introduced by the seminal contribution of Schelling (1960).

The strategic use of managerial incentive contracts has been introduced by Vickers (1985), Fershtman (1985), Fershtman and Judd (1987) and Sklivas (1987) or VFJS here forth. In these papers, each owner has the opportunity to compensate his manager with an incentive contract combining own profits and sales or revenues, in order to direct him to a more aggressive behavior in the market. Early empirical studies (Baker et al., 1988; Jensen and Murphy, 1990; Lambert et al., 1991) suggest that CEO compensation is positively associated with both profit and sales. Industry level analyses suggest that contracts of this type are widely adopted in the CEO compensation practice in US markets with high R&D investments such as the "new economy" firms (Nourayi and Daroca, 2008), the US electric utility industries (Duru and Iyengar, 1999).[2]

The strategic delegation of both short run and long run decisions such as R&D investments was introduced by Zhang & Zhang (1997). They examine strategic delegation assuming that owners exogenously select either to delegate both type of decisions or none. Yet, empirical evidence show that some firms' owners tend to delegate only short-run decisions to their managers, while others delegate long-run decisions as well (Colombo and Delmastro, 2004).

Our paper differentiate from the relevant literature by permitting firms' owners to endoge-

[1] See for instance, Sappington (1991), Stiglitz, (1987), Rees, (1985, A) and (1985, B) for a rigorous review.

[2] This justifies our choise to connect managerial delegation of R&D investments to the VFJS managerial compensation modeling.

nously select between two alternative strategies: either Full Delegation (FD), in which they delegate both short-run (output) and long-run (R&D investments) decisions to their managers or Partial Delegation (PD), in which case they delegate only short-run decisions to their managers. In particular the present paper attempts to address the following questions. First, which are the strategic interactions that arise between duopolistic firms, when firms owners' alternative strategies are either Full Delegation or Partial Delegation? Second, which strategy will prevail in equilibrium? More specifically is the equilibrium sensitive to the assumption of existence of ex ante commitment of firms' owners regarding to the strategy that they will follow? Third, which are the welfare effects of each delegation configuration?

In order to address the above questions we assume a duopolistic industry in which firms compete in quantities (short-run decisions) and cost reducing R&D investments (long-run decisions). Firms owners' alternative strategies are either Full Delegation (FD) or Partial Delegation (PD). We consider three possible equilibrium configurations: First, the Universal Full Delegation (FD, FD) configuration, in which both rival owners choose Full Delegation. Second, the Universal Partial Delegation (PD, PD), in which both owners select Partial Delegation. Third, the Coexistence Delegation configuration (FD, PD) in which one owner chooses the Full Delegation scheme, while his rival selects the Partial Delegation scheme.[3] The analysis over the equilibrium has been motivated by a key assumption of the relevant literature: Firms' owners commit over the types of contracts that they choose to compensate their managers. Then, we ask whether the results obtained with ex-ante commitment still hold without commitment.[4]

Regarding the first question, we find that R&D investments are higher under the Universal FD than under the Universal PD configuration. If the initial marginal cost is relatively low, the profits of the firms are higher under Universal FD than under Universal PD. However, this result is reversed when the initial marginal cost is larger. The firm that follows the FD strategy in the Coexistence configuration invests more in R&D and has higher profits than in both the Universal FD and PD scenarios, while the opposite holds for the firm that follows the PD strategy.

Regarding the second question, we find that if rival owners can commit to their delegation schemes, the Universal FD is the only equilibrium configuration, independently of the initial

[3] It is straightforward from the VFJS model that, for given technologies, delegation of decisions from owners to managers is always the dominant strategy. Henceforth, subgames in which an owner delegates no decisions to his manager and sticks to pure profit maximization (No Delegation) are considered only as a benchmark.

[4] See for instance Manasakis et al. (2010).

marginal cost. However, if we assume that there is no ex ante commitment, the following results hold: the Universal PD is never an equilibrium configuration. If the initial unit cost is relatively high, the Universal FD the only equilibrium configuration. Otherwise, the equilibrium configuration is asymmetric where one firm uses a FD scheme, while the rival uses a PD scheme.

Regarding welfare, our main finding is that any equilibrium Delegation configuration leads to higher welfare than the benchmark Cournot case, in which both owners decide not to delegate any decision to their managers. The reason behind this result is that Delegation schemes lead to higher output and consumers' surplus which compensates for the decrease in the overall firms' profitability due to higher competition comparing to No Delegation. Moreover, welfare is lower in the FD scheme than in the PD one, due to overinvestment in R&D under FD.

Our paper contributes to a recent branch of the strategic delegation literature which studies how strategic delegation affects firm's R&D investments and production decisions assuming that there is ex ante credible commitment of firms' owners regarding to the strategy that they will follow. Zhang & Zhang (1997) and Z. Zhang (2002) consider a Cournot duopoly in which either the Full Delegation or the No Delegation strategy are chosen exogenously. They find that, under the Full Delegation strategy, if R&D spillovers are low, firms invest more in cost-reducing R&D and produce higher output comparing to No Delegation. The opposite holds for high R&D spillovers. However, firms always obtain lower profits under Full Delegation than under No Delegation.[5] In a similar context, Lambertini (2004) examines an asymmetric case in which the owner of one firm selects No Delegation, while his rival chooses Full Delegation. He finds that the latter firm invests more in R&D and has higher output and profits, than the former, for all spillover rates. Kopel & Riegler (2005) endogenize the selection between No Delegation and Full Delegation, by assuming credible commitment between the rival owners. Their main finding is that R&D spillovers do not affect firms' owners equilibrium strategy, which is to choose Full Delegation. Our work departs from the above literature in three ways. First, we extend owners' strategy space by also including Partial Delegation as a possible owners' strategy. Hence, in our model owners endogenously choose between Full or

[5] Kopel & Riegler (2006) amend the solution concept of Zhang & Zhang (1997), indicating that due to computational mistakes, some of their propositions do not hold.

Partial Delegation.[6],[7] Second, we study both the cases under the existence or not, of ex ante commitment ability of firms' owners regarding to the strategy that they will follow. Third, we also consider the welfare effects of each delegation strategy.[8]Our paper is also close to Barcena-Ruiz and Casado-Izaga (2005). They examine whether the owners of firms have incentives to follow Full or Partial Delegation when the long-run decision is firms' location and that the rival firms compete in prices, assuming that owners can commit to delegation strategies and they offer VFJS incentive schemes to their managers. Their main finding is that firms' owners always choose the Partial Delegation strategy. In contrast, we show that if firms compete in strategic substitutes, such as quantities, Partial Delegation never arises in equilibrium, with or without credible commitment over the firms' owners' strategy.

The rest of the paper is organized as follows: Section 2 presents the model. In Section 3, the different subgames are analyzed and a comparative analysis is conducted. In Section 4, the conditions under which alternative delegation configurations emerge in equilibrium are investigated. In Section 5, welfare analysis is conducted, while in Section 6, the case in which there is credible commitment about the type of the decisions that owners delegate to managers is examined. Section 7 provides some concluding remarks.

2 The Model

We consider a homogenous good industry where two firms, denoted by $i, j = 1, 2, i \neq j$, compete in quantities. The (inverse) demand function for the final good is given by $P(Q) = A - Q$, where $Q = q_1 + q_2$ is the aggregate output.

By following D'Aspremont and Jacquemin (1988), we assume that firms are endowed with constant returns to scale technologies and their marginal cost is initially equal to C ($C < A$). Firm i, by investing $\frac{rx_i^2}{2}$ in R&D activities, can decrease its marginal cost to $C - x_i$. The total cost function for firm i is $C_i(.) = (C - x_i)q_i + \frac{rx_i^2}{2}$. This quadratic R&D cost specification

[6] We also consider No Delegation as a benchmark. However, this never appears in equilibrium.

[7] This is based on empirical evidence which show that some firms' owners tend to delegate only short-run decisions to their managers, while others delegate long-run decisions as well (Colombo and Delmastro, 2004). Their results, however, are inconclusive regarding the prevailing delegation scheme that owners will prefer in equilibrium. This justifies to some extent the existence of an asymmetric equilibrium where one firm chooses Full Delegation and the other Partial Delegation in our findings.

[8] Based on the findings of Kopel & Riegler (2005), in our paper, we assume that there are no R&D spillovers. This allows us to concentrate our analysis on alternative factors that may affect owners' choice on the type of decisions delegated, such as their ability to commit to specific delegation schemes.

implies diminishing returns to R&D expenditures. The parameter r reflects the effectiveness of the R&D technology on the marginal cost reduction. A higher r denotes a less effective R&D technology: the higher the r, the higher the required expenditure to obtain a given marginal cost reduction. To guarantee well-behaved interior solutions in all cases we make the following assumption:

Assumption 1: $\frac{1}{4} \leq c = \frac{C}{A} \leq 1$ and $r \geq \underline{r} = 2.25$.

$c = \frac{C}{A}$ indicates the efficiency of the initial technology relative to the market size. That is, the initial marginal cost should not be too low, so that firms have incentives to reduce it by spending in cost reducing R&D. Moreover the effectiveness of an R&D investment should not be too high, otherwise firms would have incentives to reduce their marginal cost to zero.

Thus, firm i's profits are given by:

$$\Pi_i = (A - q_i - q_j)q_i - (C - x_i)q_i - \frac{rx_i^2}{2}, \; i, j = 1, 2; \; i \neq j \tag{1}$$

In this industry, each firm has an owner and a manager. Following Fershtman and Judd (1987), "owner", is a decision maker whose objective is to maximize the profits of the firm. This could be the actual owner, a board of directors, or a chief executive officer. "Manager" refers to an agent that the owner hires to make real time operating decisions.[9] Each firm's owner has the opportunity to compensate his manager by offering to him a "take-it-or-leave-it" incentive contract.[10] Under this contract, the incentive structure takes a particular form: the risk-neutral manager i is paid at the margin, in proportion to a linear combination of own profits and own sales. In particular the manager of firm i will be given an incentive to maximize:

$$M_i = a_i\Pi_i + (1 - a_i)R_i \tag{2}$$

[9] One can argue that moral hazard issues may occure in a strategic delegation setting. However, this problem is out of scope of this branch of the literature. More specifically, strategic delegation literature focuses on the use of delegation of authority from owners in order to render credible non strictly profit maximizing strategies that managers can employ,which the former themselves are unwilling to choose. See Vickers (1985), Fershtman and Judd (1987), Sklivas (1987), Miller and Pazgal (2001; 2002; 2005), Jansen et al. (2007; 2009) and Ritz (2008).

[10] In the strategic delegation literature, it is a regular assumption that firms' owners have all the bargaining power during negotiations with their managers, i.e., they offer to their managers "take-it-or-leave-it" incentive contracts (see the references cited in the previous footnote).

where Π_i and R_i are firm i's profits and revenues respectively.[11] a_i is the *managerial incentive parameter* that is chosen optimally by firm i's owner so as to maximize his profits. We assume that $a_i \in (0, 1]$. Observe that if $a_i = 1$, manager i's behavior coincides with owner i's objective for strict profit-maximization. If $a_i^{PR} < 1$, firm i's manager moves away from strict profit-maximization towards including consideration of sales and thus, he becomes a more aggressive seller in the market. Hence, the higher the managerial incentive parameter set by owner i, the lower the aggressiveness of his manager and the lower the output level that the latter sets.

In order to examine which types of decisions will firms' owners delegate to their managers in equilibrium, we consider a four-stage game with observable actions:[12] In the first stage, both firms' owners, simultaneously and independently, choose whether to delegate both the R&D investments and the quantity decisions to their managers (Full Delegation strategy, FD), or the quantity decisions solely (Partial Delegation strategy, PD). If an owner chooses the FD strategy, he also sets the managerial incentive parameter in the first stage of the game and at the second stage, his manager decides over the R&D investments. If instead, the owner has chosen the PD strategy, he takes no action in the first stage of the game and in the second stage, it is the owner himself who decides over the R&D investments. In the third stage, the owner who has chosen the PD strategy sets the managerial incentive parameter for his manager, while the owner who has chosen the FD strategy takes no action. In the last stage, managers compete in quantities. The above game is solved backwards by employing the Subgame Perfect Nash Equilibrium (SPNE) solution concept.[13,14] Figure 1 visualizes the timing of the game.

Due to symmetry, the number of candidate equilibria is reduced to three, namely: *Universal Full Delegation* (FD, FD), *Universal Partial Delegation* (PD, PD), *Coexistence scenario* (FD,

[11] Following Fershtman and Judd (1987), U_i^{PR} will not be the manager's reward in general. Since the manager's reward is linear in profits and sales, he is paid $A_i + B_i U_i^{PR}$ for some constants A_i, B_i, with $B_i > 0$. Since he is risk-neutral, he acts so as to maximize U_i^{PR} and the values of A_i and B_i are irrelevant.

[12] A crucial assumption of the relevant literature is that delegation is observable. Katz (1991) argues that unobservable contracts have no commitment value at all. Fershtman and Judd (1987) support that even if contracts are not observable, they will become common knowledge when the game is being repeated for several periods. More recently, Kockesen and Ok (2004) argue that to the extent that renegotiation is costly and/or limited, in a general class of economic settings, strategic aspects of delegation may play an important role in contract design, even if the contracts are completely unobservable.

[13] It is important to note that the timing of the game is formalized as above, because in the real business world it is common practice first to decide over the long-run plans of the firm and, according to them, decide about the short-run issues. See for instance Zhang and Zhang (1997).

[14] Here, the sequence of decisions is set this way, so that the R&D investments and output decisions are taken simultaneously. Also see Barcena-Ruiz and Casado-Izaga (2005) for a similar timing.

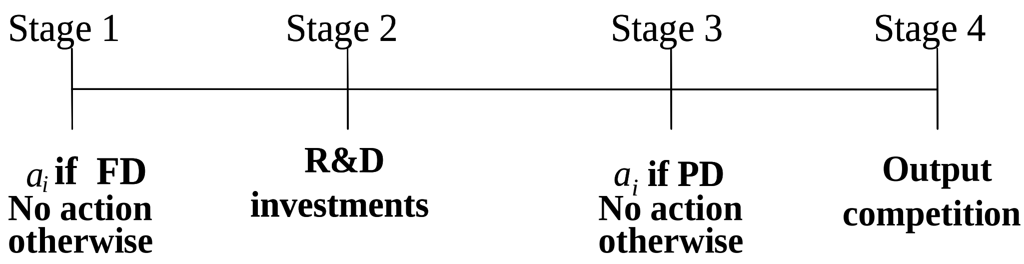

Figure 1: The timing of the game.

PD).

3 Candidate Equilibrium Schemes.

3.1 No Delegation.

Before proceeding to the candidate equilibrium analysis, we briefly discuss the benchmark case. This is the "No-delegation" scheme in which production and R&D decisions are taken by firms' owners. In this case, the reaction function in the output competition stage is $RFq_i^c(q_j^c) = \frac{A-q_j-(C-x_i)}{2}$ and the respective in the R&D investments stage is $RFx_i^c(x_j^c) = \frac{4(A-C-x_j)}{(9r-8)}$. Moreover, equilibrium output, R&D, profits and total welfare are $q_i^c = \frac{3r(A-c)}{9r-4}$; $x_i^c = \frac{4(A-c)}{9r-4}$; $\Pi_i^c = \frac{r(9r-8)(A-c)^2}{(9r-4)^2}$ and $TW^c = \frac{4r(A-c)^2}{9r-4}$ respectively.

3.2 Universal Full Delegation: (FD, FD).

Let us consider the Universal FD configuration. In the last stage of the game, given the R&D investments and the managerial incentive parameters, each manager sets output to maximize (2). From the first order condition, the reaction function of manager i is:

$$RFq_i^{FD}(q_j) = \frac{A - q_j - a_i(C - x_i)}{2} \tag{3}$$

Observe that manager i considers $a_i(C - x_i)$ as the marginal cost of production. For $a_i \in (0, 1]$, this marginal cost is lower than that considered by the owner himself in the benchmark case of No-delegation. Thus, the lower the managerial incentive parameter that owner i sets, the lower the marginal cost that manager i considers. This results in a relatively fiercer aggressiveness of manager i who, in turn, sets output at a higher level. Note also that the slope of manager i's reaction curve is $\frac{\theta RFq_i^{FD}}{\theta q_j} = -\frac{1}{2} = \frac{\theta RFq_i^{C}}{\theta q_j}$, implying that the manager's reaction curve is an outward and parallel shift of the respective curve in the benchmark case of No-delegation.

Taking the first order conditions and solving the system of equations, firm i's output is:

$$q_i^{FD}(x_i, x_j, a_i, a_j) = \frac{A + a_j(C - x_j) - 2a_i(C - x_i)}{3} \tag{4}$$

The following observations are in order: First, $\frac{\theta q_i^{FD}}{\theta a_i} = -\frac{2(C-x_i)}{3} < 0$ implies that the higher the managerial incentive parameter that owner i sets, the lower the aggressiveness of his manager and the lower the output level that the latter sets. Second, $\frac{\theta q_i^{FD}}{\theta a_j} = \frac{(C-x_i)}{3} > 0$ suggests that since quantities are strategic substitutes, the lower the aggressiveness of manager j, the lower the output level that he sets and the higher the output level set by the rival manager i, in order to obtain a competitive advantage in the final-good market. Third, $\frac{\theta q_i^{FD}}{\theta x_i} = \frac{2a_i}{3} > 0$ and $\frac{\theta q_i^{FD}}{\theta x_j} = -\frac{a_j}{3} < 0$, i.e., as manager i increases his R&D effort, he also increases firm i's output level, by pushing outwards firm i's output reaction curve. Since quantities are strategic substitutes, an immediate consequence will be the reduction of the rival firm j's output level.

In the second stage, each manager i invests in R&D so as to maximize his utility, given by $M_i(x_i, x_j, a_i, a_j) = [q_i^{FD}(\cdot)]^2 - a_i r x_i^2$. From the first order condition, the reaction function of manager i is:

$$RFx_i^{FD}(x_j) = \frac{4[A - 2a_i c + a_j(C - x_j)]}{(9r - 8a_i)} \tag{5}$$

$\frac{\theta RFx_i^{FD}}{\theta x_j} = \frac{-4a_j}{9r-8a_i} < 0$ suggests that rival firms' R&D efforts are strategic substitutes. Note also that $\frac{\theta RFx_i^{FD}}{\theta x_j} > \frac{\theta RFx_i^{C}}{\theta x_j} = \frac{-4}{9r-8}$, i.e., manager i's best response in R&D effort against manager j is fiercer than the respective of owner i against owner j in the No-delegation benchmark.

Taking the first order conditions and solving the system of equations, firm i's R&D investments are:

$$x_i^{FD}(a_i, a_j) = \frac{12r(A - 2a_iC + a_jC) - 16a_j(A - a_iC)}{27r^2 - 24r(a_i + a_j) + 16a_ia_j} \quad (6)$$

$\frac{\theta x_i^{FD}}{\theta a_i} = \frac{8(2a_j-3r)(4a_j-3r)(4A-9Cr)}{[27r^2+16a_ia_j-24(a_i+a_j)]^2} < 0$ implies a positive relationship between the aggressiveness of manager i and the level of R&D investments he chooses. Further more, $\frac{\theta x_i^{FD}}{\theta a_j} = \frac{12r(4a_i-3r)(4A-9Cr)}{[27r^2+16a_ia_j-24(a_i+a_j)]^2} > 0$ suggests that the highest a_j, thus the lower the aggressiveness of manager j, the highest the R&D investments set by manager i, in order to obtain competitive advantage in the market.

In the first stage of the game, each owner i chooses a_i so as to maximize profits given by $\Pi_i(a_i, a_j) = [q_i^{FD}(\cdot)]^2$. From the first order condition, the reaction function of owner i is:

$$RFa_i^{FD}(a_j) = \frac{A(3r - 4a_j)[3r(16 + 9r) - 32a_j] - 3Cr[128a_j^2 - 300ra_j + 27r^2(6 - a_j)]}{4(3r - 2a_j)\{6A(3r - 4a_j) - C[3r(4 + 9r) - 2a_j(4 + 27r)]\}} \quad (7)$$

We find that $\frac{\theta RFa_i^{FD}}{\theta a_j} < 0$.[15] Given the analysis after (4) and (6) this suggests that as owner i directs his manager towards a relatively less aggressive behavior, the rival owner manipulates his manager's behavior reversely in order to increase the latters R&D investments and output and therefore increase his profitability.

Setting $c = \frac{C}{A}$, and exploiting symmetry ($a_i = a_j$), the equilibrium managerial incentive parameter is:

$$a_i^{FD} = \frac{8(9 + 4r) - 3cr(45r + 44) + \Psi}{8[12 - c(27r + 4)} \quad (8)$$

Where,

$\Psi = \sqrt{1024 - 4608r - 96rc(9r - 28)(9r - 2) + 9r^2c^2[784 + 9r(225r - 784)]}$.

Using a_i^{FD}, we get respectively each firm's equilibrium R&D investments, output, and profits:

$$x_i^{FD} = \frac{3r[48 - c(45r - 4)] - 32 + \Psi}{24r(9r - 2)} \quad (9)$$

[15] $\frac{da_i^R}{da_j} < 0$ was obtained through numerical simulations. Further details are available from the authors upon request.

$$q_i^{FD} = \frac{3r[48 - c(45r - 4)] - 32 + \Psi}{32(9r - 2)} \tag{10}$$

$$\Pi_i^{FD} = [4rc(9r - 8)(27r - 4) - 6r\Psi - 3r^2c^2(9r - 8)(45r - 4) + rc(9r + 4)\Psi] * \Omega \tag{11}$$

Where $\Omega = \frac{[c(288r+64+\Psi)-3c^2r(45r+44)-96]}{8\{32+3r[c(117r-20)-48]+\Psi\}^2}$.

3.3 Universal Partial Delegation: (PD, PD).

We consider next the Universal Partial Delegation configuration. In the first stage there is no action. In the second stage, owners decide their R&D investments. In the third stage owners set the incentive schemes for their managers, while, in the last stage, each manager sets output to maximize (2). The last stage replicates the analysis of the corresponding stage in the Universal Full Delegation case.

In the third stage of the game, each owner i chooses a_i so as to maximize profits given by $\Pi_i(a_i, a_j, x_i, x_j) = [q_i^{PD}(\cdot)]^2$. From the first order condition, the reaction function of owner i is:

$$RFa_i^{PD}(a_j) = \frac{(6 - a_j)C - 6x_i + a_jx_j - A}{4(C - x_i)} \tag{12}$$

Note again that like in the Universal Full Delegation case, managerial incentives are strategic substitutes, since $\frac{\theta RFa_i^{PD}}{\theta a_j} = -\frac{C-x_j}{4(C-x_i)} < 0$.

Taking the first order conditions and solving the system of equations, we obtain the equilibrium managerial incentive parameter a_i:

$$a_i^{PD}(x_i, x_j) = \frac{2(3C - 4x_i) + 2x_j - A}{5(C - x_i)} \tag{13}$$

It occurs again that R&D investments and managerial incentives are strategic substitutes, since $\frac{\theta a_i^{PD}}{\theta x_i} = -\frac{A+2(C-x_j)}{5(C-x_i)^2} < 0$ and $\frac{\theta a_i^{PD}}{\theta x_j} = \frac{2}{5(C-x_i)} > 0$. Thus, as owner i increases his R&D investments in the second stage, he then sets a_i at a relatively low level in the next stage, directing his manager to a relatively aggressive behavior in order to exploit the marginal cost reduction. Since managerial incentives are strategic substitutes $\left(\frac{\theta a_i^{rPD}}{\theta a_j} < 0\right)$, as owner i decreases a_i, owner j's best response will be to direct his manager towards a relatively less aggressive behavior, i.e., increasing a_j.

In the second stage, owners simultaneously set their R&D investments so as to maximize their profits, given by $\Pi_i(x_i, x_j) = [q_i^{PD}(\cdot)]^2$. From the first order condition, the reaction function of owner i is:

$$RFx_i^{PD}(x_j) = \frac{12(A - C - 2x_j)}{25r - 36} \tag{14}$$

Note again that the strategic substitutability between rival firms' R&D investments is confirmed,since $\frac{\theta RFx_i^{PD}}{\theta x_j} = -\frac{24}{25r-36} < 0$. By exploiting symmetry and setting $c = \frac{C}{A}$, we obtain the equilibrium R&D investments:

$$x_i^{PD} = \frac{12(1-c)}{25r - 6} \tag{15}$$

Using a_i^{PD}, we get respectively each firm's equilibrium managerial incentive parameter, output, and profits:

$$a_i^{PD} = \frac{(30c - 5)r - 12}{25cr - 12} \tag{16}$$

$$q_i^{PD} = \frac{10r(1-c)}{25r - 12} \tag{17}$$

$$\Pi_i^{PD} = \frac{2r(25r - 36)(1-c)^2}{(25r - 12)^2} \tag{18}$$

At this point, it is interesting to investigate the way that the different delegation strategies affect the R&D investments, the managerial incentive parameters, as well as output and profits, in the two symmetric delegation configurations.

Proposition 1: *In a symmetric delegation game:*

(i) *When there is Universal Full Delegation, firms always invest more in R&D than when there is Universal Partial Delegation ($x^{FF} > x^{PP}$).*

(ii) *When there is Universal Full Delegation, managers are manipulated by owners to be less* *aggressive, than when there is Universal Partial Delegation* ($a^{FF} > a^{PP}$).

(iii) *If* $c \in [0.25, 0.54)$*, firms produce lower output when there is Universal Full Delegation, than when there is Universal Partial Delegation* ($q^{FF} < q^{PP}$)*. The opposite holds if* $c \in [0.54, 1)$.

(iv) *If* $c \in [0.25, 0.46)$*, then firms make higher profits when there is Universal Full Delegation than when there is Universal Partial Delegation* ($\Pi^{FF} > \Pi^{PP}$)*. The opposite holds if* $c \in [0.46, 1)$.

For proof see Appendix.

The rational behind (i) is obvious. More specifically, in the Universal FD configuration firms' managers decide over R&D investments. Concerserly in the Universal PD configuration profit maximizing owners decide over R&D investments. Since managers are manipulated to be more aggressive than strict profit maximization, R&D investments will be higher under universal FD.

The insight behind (ii) is the strategic substitutability between R&D investments and managerial incentives. Thus, increased R&D investments lead to better technology and to less aggressiveness during the quantity competition case in the Universal FD configuration, than in the PD one. Hence, in the Universal FD owners will set a higher managerial incentive parameter in order to stimulate their managers to become less aggressive, comparing with the Universal PD configuration.

The intuition behind firms' output is the output effect in R&D investments.[16] More specifically, from Proposition 1(i) and (ii) it becomes clear that there are two opposite effects on output. First, in the Universal FD configuration, firms will invest more in R&D acquiring better technology, which leads to higher output, than in the Universal PD. Second, in the Universal FD owners will typically choose softer incentive schemes for their managers, causing lower output comparing with the Universal PD configuration. For relatively low initial unit cost i.e. $c \in [0.25, 0.54)$, the dominant effect is the second one. However, if the initial marginal cost is high i.e. $c \in [0.54, 1)$, given R&D investments, the dominant effect is the first one, since the gain from the reduction of the marginal cost increases, if production is amplified. Therefore, under a relatively high initial unit cost, firms that have invested more in R&D at

[16] See Bester & Petrakis (1993).

the early stages of the game (that is, in the Universal FD), tend to produce more, in order to increase the benefit from the technology improvement.

The rationale regarding profits is that from above analysis there are three effects on firms' profitability. First, in the FD strategy, firms will have higher R&D expenses, which increase cost and reduce their profitability, comparing with the PD scheme. Second, in the FD strategy, owners will typically choose softer incentive schemes for their managers, which increase firms' profits, since it weakens the prisoners' dilemma effect comparing with the PD scheme. Third, overproduction by both firms under strategic delegation regimes is negatively connected to their profitability. For $c \in [0.25, 0.46)$, higher output and fiercer market competition in the Universal PD configuration lead to lower profits, compared with the Universal FD configuration. For $c \in [0.46, 1)$, higher output and R&D expenses under the Universal FD configuration lead to the opposite result.

3.4 Coexistence of Delegation Schemes: (FD, PD).

In the Coexistence configuration, without loss of generality, we assume that owner i follows the Full Delegation strategy, while his rival chooses the Partial Delegation strategy. It the first stage, owner i selects the managerial incentives for his manager, while his rival takes no action. Then, in the second stage, manager i and owner j simultaneously set their R&D investments. proceeding in the third stage, owner j set the incentives for his manager and then, in the last stage, managers engage in output competition.

The reaction functions and the equilibrium output values of the last stage are given by (3) and (4), respectively.

In the third stage, owner j optimally chooses a_j so as to maximize his profits. From the first order condition, the reaction function of owner j is:

$$a_j^A(x_i, x_j, a_i) = \frac{6}{4} - \frac{A + a_i(C - x_i)}{4(C - x_j)} \tag{19}$$

In the present scenario, the strategic substitutability of managerial incentives $\left(\frac{\theta RFa_j^A}{\theta a_i} = -\frac{c-x_i}{4(c-x_j)} < 0\right)$ further suggests that owner i is the leader in incentives, since he sets the managerial incentive parameter in advance. Furthermore, $\frac{\theta a_j}{\theta x_j} = -\frac{A+a_i(c-x_i))}{4(C-x_j)^2} < 0$ and $\frac{\theta a_j}{\theta x_i} = \frac{a_i}{4(C-x_j)} > 0$ replicate our earlier arguments according to which, high R&D investments by manager i in the second stage of the game, will cause owner j to direct his manager to a relatively less aggressive behavior.

In the second stage manager i and owner j choose R&D investment levels, so as the former to maximize his compensation and the latter his profits.From the first order conditions, the reaction functions of manager i and owner j are respectively:

$$RFx_i^A(x_j) = \frac{3[A - C(2 - 3a_i) - 2x_j]}{8r - 9a_i} \tag{20}$$

$$RFx_j^A(x_i) = \frac{A - (2 - a_i) - a_i x_i}{2(r - 1)} \tag{21}$$

Note again that since $\frac{\theta RFx_i^A}{\theta x_j} = -\frac{6}{8r-9a_i} < 0$, $\frac{\theta RFx_j^A}{\theta x_i} = -\frac{a_i}{2(r-2)} < 0$, high R&D investments by manager i will lead owner j to set low R&D investments in the second stage.

Taking the first order conditions and solving the system of equations, firm i's and j's R&D investments are:

$$x_i^A(a_i) = \frac{6(A - a_i C) - 3r[A + C(2 - 3a_i)]}{8r(r - 1) - 3a_i(3r - 2)} \tag{22}$$

$$x_j^A(a_i) = \frac{3a_i(A - C) - 4r[A - C(2 - a_i)}{3a_i(3r - 1) - 8r(2r - 1)} \tag{23}$$

In the first stage owner i maximizes his profits with respect to a_i. By solving the foc and setting $c = \frac{C}{A}$, we obtain the equilibrium managerial incentive parameter for manager i:

$$a_i^A = \frac{(r - 2)[r(8r + 9] - 6] - 2cr[r(16r - 49 + 22]}{(3r - 2)\{6(r - 2) - c[r(8r - 19) - 6]\}} \tag{24}$$

Using a_i^A, we get respectively each firm's equilibrium R&D investments, output, and profits:

$$a_j^A = \frac{r\{28 + 9r - 4r^2 + 4c[r(7r - 25) + 10]\} - 12}{r\{34 - 8r + c[r(24r - 83) + 34]\} - 12} \tag{25}$$

$$x_i^A = \frac{6(r - 2)(1 - c)}{r(8r - 25) + 6};\ x_j^A = (1 - c)[\frac{1}{3r - 2} - \frac{3}{r(8r - 25) + 6}] \tag{26}$$

$$q_i^A = \frac{4r(r-2)(1-c)}{r(8r-25)+6};\ q_j^A = \frac{2r(1-c)[r(2r-17)+6]}{(3r-2)[r(8r-25)+6]} \tag{27}$$

$$\Pi_i^A = \frac{2r(r-2)^2(1-c)^2}{(3r-2)[r(8r-25)+6]};\ \Pi_j^A = \frac{2r(r-1)(1-c)^2[r(4r-17)+6]^2}{(3r-2)[r(8r-25)+6]^2} \tag{28}$$

By comparing the equilibrium values of R&D investments, managerial incentive parameter, output and profits in the Coexistence configuration, with the ones obtained in both the symmetric delegation configurations (Universal FD and Universal PD) the following Proposition derives:

Proposition 2: *When there is the Coexistence configuration,the owner of firm $i(j)$ increases (decreases) the aggressiveness of his manager, compared with both symmetric delegation configurations . Thus, firm $i(j)$ invests more (less) in R&D, produces higher (lower) output and has higher (lower) profits, comparing with its competitor and both symmetric delegation configurations, always. The following inequalities hold:*

$a_j^{FP} > a^{FF} > a^{PP} > a_i^{FP}$

$x_i^{FP} > x^{FF} > x^{PP} > x_j^{FP}$

$q_i^{FP} > q^{FF} > q^{PP} > q_j^{FP}$,if $c \in [0.54, 1)$

$q_i^{FP} > q^{PP} > q^{FF} > q_j^{FP}$, if $c \in [0.25, 0.54)$

$\Pi_i^{FP} > \Pi^{FF} > \Pi^{PP} > \Pi_j^{FP}$, if $c \in [0.25, 0.46)$

$\Pi_i^{FP} > \Pi^{PP} > \Pi^{FF} > \Pi_j^{FP}$, if $c \in [0.46, 1)$

The intuition behind this result is that, since owner i sets the managerial incentives for his manager first, he becomes leader in incentives. Given the strategic substitutability between managerial incentives, owner i has the chance to obtain competitive advantage over his competitor by increasing the aggressiveness of his manager in the first stage. Hence, in the subsequent stages of the game, manager i invests more in R&D, produces higher output than his competitor. Additionally, strategic substitutability between managerial incentives, R&D investments and output, lead owner j to invest less in R&D and set less aggressive incentives for his manager. Therefore, manager j produces less output than his rival. Hence, the owner of firm i earns higher profits than his competitor who has chosen partial delegation. An interesting observation is that from (24) one obtains that if $c \in [0.25, 0.44)$ then $a_i^{FP} \leq 0$. This means that owner i gives a negative weight on profits (hence even higher weight on sales) in his manager's utility, in order to induce a more aggressive behavior by the latter and hence strengthen his leadership in incentives.

4 Equilibrium Analysis.

Literature so far consider only symmetric results in equilibrium by assuming existence of credible commitment between the rival owners when they select their delegation strategy. That is, firms are always both choose either Full or Partial Delegation. However, empirical evidence by Colombo and Delmastro (2004) show that in some cases Coexistence between the two strategies appears often in equilibrium. We show that by altering the commitment assumption, in some cases Coexistence scenario appears equilibrium. Let us unravel the analysis that drives our results.

4.1 Equilibrium under commitment.

Following the bulk of the literature in the subject, in this subsection we examine the equilibrium results if we assume there exists credible commitment between the rival owners when they select their delegation strategy. Hence, we now add a stage zero, in which owners commit over the strategy that they will select. As argued above, there are three different subgames: the first one is the Universal FD configuration, the second one refers to the Universal PD one, while the third one is the Coexistence configuration.

By considering Proposition 2, the Full Delegation strategy dominates the Partial Delegation one. More specifically, if one owner selects the Partial Delegation strategy, then the best response of the competing firm's owner is to select the Full Delegation one. This way the latter has the opportunity to become leader in incentives and dominate the market since $\Pi_i^{FP} > \Pi^{PP}$. Hence, no owner will select the Partial Delegation strategy. Furthermore, if one owner selects the Full Delegation strategy, then the best response of the competing firm's owner is to select the Full Delegation one, as well. Otherwise, the latter will become follower in incentives and will obtain relatively low profits, since $\Pi^{FF} > \Pi_j^{FP}$. Therefore, under the assumption of credible commitment between the competing owners, Universal Full Delegation is the unique equilibrium configuration. The following Proposition summarizes:

Proposition 3: *Assuming the existence of ex-ante commitment ability between the rival own-*

ers over the type of decisions they will delegate to their managers, Universal Full Delegation is the unique equilibrium configuration.

4.2 Equilibrium under no commitment.

In this subsection the determination of the equilibrium delegation configuration is analyzed, under the assumption that there is no ex-ante commitment between the rival owners regarding the strategy they will follow. We argue that firms' owners cannot ex-ante commit to a specific strategy, but they rather maximize profits at each moment of time. This implies that each owner chooses the best strategy in order to maximize profits at each point in time and is unable to commit to any time inconsistent strategy. As is standard we first propose a candidate equilibrium configuration, and then check whether it survives or not all possible deviations. Thus, we need to examine owners' incentives to unilaterally deviate from each of the above candidate equilibrium configurations. The way we precede is as follows: given that the owner of firm 1 has chosen one of the above strategies (PD or FD), the owner of firm 2 examines his profitability, if he switches to a strategy different from the one specified for each candidate equilibrium configuration. Let us analyze how the commitment assumption

4.2.1 Universal Full Delegation as a candidate equilibrium.

Universal Full Delegation is an equilibrium when no owner has incentives to unilaterally deviate from the FD towards the PD strategy. The deviation game unravels as follows: given the fact that firm 1's owner delegates both short-run and long-run decisions to his manager, supposing that firm 2's owner will do the same, the latter deviates by delegating only short-run decisions to his manager. At the first stage of the deviation game firm 1's owner sets the managerial incentive parameter $a_1 = a^{FF}$, while firm 2's owner postpones his decision. In the next stage R&D decisions are taken by manager 1 and owner 2, following which, owner 2 sets the incentive parameter of his manager optimally. Finally in the last stage both firms' managers compete in quantities. In this case, the solution concept of the deviation game coincides with the one in the Coexistence configuration, except that, in the first stage owner 1 will set $a_1 = a^{FF}$ presuming that firm 2's owner will do the same. By substituting $a_1 = a^{FF}$ in (22), (23), (5) and (1), the deviant firm's profits are given by Π_2^d.[17]

By comparing the deviant owner's profits, Π_2^d, with the profits that result in the Universal FD Π^{FF} we obtain that $\Pi_2^d > \Pi^{FF}$if $c \in [0.36, 1)$and $\Pi_2^d < \Pi^{FF}$ if $c \in [0.25, 0.36)$. Given Proposition (i) and (ii), if the initial unit cost is relatively high, no firm's owner has incentives to deviate from the Universal FD in order to benefit from the reduction of the unit cost via increased R&D investments , during the forthcoming market competition stage. However, if the initial unit cost is relatively low then both firm's owners have incentives to deviate from FD to PD, so as to reduce their R&D expenditures, since if the initial cost is low, the gain from the reduction of the marginal cost via is also low.

4.2.2 Universal Partial Delegation as a candidate equilibrium.

We next propose as a candidate equilibrium the Partial Delegation configuration. In order to test the stability of this configuration the following deviation game is considered: given owner 2's choice to delegate only short-run decisions to his manager, firm 1's owner examines the profitability of his firm in the case that he deviates and delegates both short-run and long-run decisions to his manager. In the first stage, owner 1 deviates and selects the managerial incentives for his manager $a_1 = a_i^{FP}$, while his rival takes no action. In the next stage, manager 1 and owner 2 set the R&D investments, following which owner 2 sets the incentives for his manager. In the final stage both managers compete in quantities.

Note that, the solution concept of this deviation game coincides with the Coexistence Delegation configuration. Hence, the deviant owner's profits are given by: $\Pi_1^d = \Pi_i^{FP}$. From Proposition 2 we have $\Pi_1^d = \Pi_i^{FP} > \Pi^{PP}$. Hence, by considering Proposition 2, both firms' owners have incentives to deviate from the Universal PD scenario towards the FD strategy, because this way they have the opportunity to become leaders in incentives and obtain a competitive advantage in the market. Hence, the Universal PD is never an equilibrium configuration.

4.2.3 Coexistence scenario as a candidate equilibrium.

In order to investigate whether the Coexistence configuration is an equilibrium, two possible deviations are examined. First, owner 1 may deviate from the FD to the PD strategy. Second, owner 2 may deviate from PD to the FD strategy.

[17] $\Pi_2^d = \frac{2r(r-1)\{24(r+4)+3[\Psi-c(3r+4)(13r+8)]+[cr(270r^2-195r+268)=(2r+3)\Psi\}^2}{\{cr[536+r(513r-1850)]+3(3r-2)\Psi-24[r(5r-26)+8]\}^2}$

In the first deviation game, under the assumption that owner 2 delegates only short-run decisions to his manager, firm 1's owner deviates by also delegating only short-run decisions to his manager. In the first stage, owner 1 decides to deviate to PD thus he takes no action, following which, both owners invest in R&D optimally. In this case the deviation game is identical to the Universal PD scenario. The rational behind this is that since owner 1 takes no action during the first stage of the game, his intention to deviate becomes common knowledge in the second stage. By considering Proposition 2 and comparing the deviation profits of owner 1 ($\Pi_1^d = \Pi^{PP}$), with the profits that the same owner obtains in the Coexistence Delegation scenario (Π_i^{FP}), we obtain that $\Pi_1^d < \Pi_i^{FP}$, always. Hence, owner 1 has no incentives to deviate towards the PD strategy.

In the second deviation game, given the fact that firm 1's owner delegates both short-run and long-run decisions to his manager, firm 2's owner deviates by also delegating both short-run and long-run decisions to his manager. This deviation game is similar to the solution concept in the Universal FD, however, now in the first stage, firm 1's owner selects the managerial incentive parameter a_1, presuming that firm 2's owner will follow the PD strategy, thus, he sets $a_1 = a_i^{FP}$. On the other hand, firm 2's owner sets the managerial incentive parameter which is the best response to his rivals choice: $a_2(a_1)$.In stage two, both managers invest in R&D, followed by both managers competing in quantities. Hence, he maximizes: $\Pi_2^d[a_1 = a_i^{FP}, a_2(a_1)]$ with respect to a_2 in order to obtain a_2^d. Plugging a_2^d in $\Pi_2^d[a_1 = a_i^{FP}, a_2(a_1)]$, we derive the deviant profits Π_2^d.[18]

By comparing the deviation profits Π_2^d, with the profits that result in the Coexistence Delegation scenario we obtain that if $c \in [0.46, 1)$ then $\Pi_2^d > \Pi_j^{FP}$, thus, owner 2 has always incentives to deviate towards the FD strategy, while if $c \in [0.25, 0.46)$ the opposite holds. Therefore, iff $c \in [0.25, 0.46)$, the Coexistence configuration is an equilibrium one. The intuition replicates the arguments after Universal Full Delegation as a candidate equilibrium.

After having examined all possible equilibrium configurations, the following Proposition summarizes our results.

Proposition 4: *For given $r \geq \underline{r}$, iff $c \in [0.36, 1)$, then the Universal Full Delegation is an equilibrium.*

[18] Due to space limits some algebraic formulas are not presented here. These are available from the authors upon request.

Iff $c \in [0.25, 0.46)$*, then the Coexistence configuration is an equilibrium.*

The Universal Partial Delegation configuration is never an equilibrium.

Note that Proposition 4 is in line with empirical evidence by Colombo and Delmastro (2004) that show in some cases Coexistence between the two strategies appears in equilibrium. Note also that if $c \in [0.36, .46]$, the game is characterized by multiplicity of equilibria. Hence, the following question arises: which configuration will finally emerge in equilibrium for $c \in [0.36, .46]$? Using the comparative results of Proposition 2 and employing focal point analysis, we conclude that for this set of values Universal FD configuration will be the final equilibrium.

5 Total Welfare

In this section we examine the welfare implications of each delegation scheme. More specifically we compare total welfare under each Delegation configuration with the corresponding values obtained in the No Delegation (ND) benchmark.

Total welfare is given by

$$TW^A = CS^A_{net} + T\Pi^A, \text{ where } A = PP, FF, FP, ND \tag{29}$$

with $CS^A_{net} = \frac{1}{2}(Q^A)^2$ being the overall net consumers' surplus, $Q^A = q^A_i + q^A_j$ the total market output and $T\Pi^A$ the industry profits for each equilibrium scenario respectively. Using equilibrium results, the corresponding total welfare values are presented in Appendix C. By comparing total welfare in each configuration the following Proposition derives:

Proposition 5: *Total welfare is always higher under all Delegation configurations comparing with the No Delegation one. In a Delegation game, the Universal Full Delegation leads to the lowest total welfare, the Coexistence scenario improves welfare, while the Universal Partial Delegation leads to the highest welfare comparing with all the Delegation configurations. Hence,* $TW^{ND} < TW^{FF} < TW^{FP} < TW^{PP}$.

Proposition 5 indicates that strategic Delegation improves welfare than in the benchmark. However, the prevailing equilibria do not lead to the highest levels of welfare that would appear under Universal Partial Delegation. A number of observations are in order: In the first part of Proposition 2, increased market competition under Delegation increases consumers' surplus and total welfare than in No Delegation. However, the latter factor combined with and overinvestment in R&D leads to lower firms' profitability and total welfare as well, than in the No Delegation case. Results in equilibrium reveal that the positive effect on total welfare is dominant. In the second part of Proposition 2, there are two factors which affect firms' profitability under Delegation. The first has to do with increased output competition under the Partial Delegation strategy. The second is connected to the overinvestment in R&D in the Full Delegation strategy. Both the aforementioned factors decrease firms profitability and total welfare also. Results in equilibrium reveal that firms' loss of profitability due to overinvestment in R&D compensate over increased output competition hence $TW^{FF} < TW^{FP} < TW^{PP}$.

6 Conclusions

The present paper focuses on the type of decisions delegated from firms owners to managers under the prism of strategic delegation in oligopoly with R&D investments. Existing literature considers that the alternative strategies of firms' owners are either Full Delegation or No Delegation. Further more it considers equilibrium analysis only under the assumption of existence of credible commitment between the rival owners. Therefore it fails to explain why empirical evidence reveal the appearance of both the FD and the PD strategies in oligopolistic markets. Finally it ignores the societal effects of Delegation.

The contribution of the present paper is threefold. First, we assume a more realistic model where firms' owners' alternative strategies are either Full Delegation, in which owners delegate both the cost reducing R&D and the quantity decisions to their managers, or Partial Delegation, in which quantity decisions are delegated to managers, while owners decide themselves about the cost reducing R&D investment. In order to examine the implications of each delegation strategy on the firms' R&D investments and market performance, we compare three possible configurations; the first one is the Universal Full Delegation, the second one refers to the Universal Partial Delegation, while the third one is the Coexistence configuration. We find that R&D investments are higher in the Universal FD than in the Universal PD configuration. If the initial marginal cost is relatively low, then firms' profits are higher in the Universal FD comparing with the Universal PD configuration. The opposite holds when the initial marginal cost is relatively high. In the Coexistence configuration, the firm that follows the FD (PD) strategy always invests more (less) in R&D, and obtains higher (lower) profits, than in both symmetric delegation configurations and its competing firm.

Second, if one assumes the existence of credible commitment, the Universal Full Delegation is the unique equilibrium configuration. However, we deviate from existing literature, by examining which one of the three alternative delegation configurations will prevail in equilibrium, assuming there is no credible commitment between the competing owners regarding the type of decisions delegated to managers. We find that if the initial unit cost is relatively high, then the Universal Full Delegation is an equilibrium configuration. If the initial unit cost is relatively low, then the Coexistence configuration arises in equilibrium. The Universal Partial Delegation is never an equilibrium configuration. This results are in line with empirical evidence that suggest that Coexistence of strategies appears. It further suggest that a key factor that determines firms owners' decision over the strategy they will follow is their firms initial marginal cost before R&D investments

Third, to our knowledge this is the first paper to analyze the effects of the Full and the Partial Delegation strategies to the welfare. Our main finding is that any equilibrium Delegation configuration is connected to higher levels of welfare comparing with the benchmark case, in which no owner delegates any decision to his manager. Moreover, in a Delegation game welfare is lower if firms' owners select the Full Delegation strategy than the Partial Delegation one.

The analysis was carried out for a duopolistic market structure. We are of the opinion that the duopolistic market reveals all essential implications, considering the firms' owners' incentives to strategically delegate their firm's decisions to managers. We are also aware of the limitations of our analysis in assuming specific functional forms. However, it is the nature of the equilibrium conditions driving our results that allows us to argue that these results will also be valid under general demand and cost functions. The use of more general forms would jeopardize the clarity of our findings, without significantly changing their qualitative character. Given the current debate about the market implications of Strategic Managerial Delegation the present paper sheds light on the type of decisions firms' owners will delegate to managers in oligopolistic markets.

Appendix

Appendix A1: Proof of Lemma 3

By comparing the SPE values of firms' output in Universal FD and Universal PD, $q^{FF} -$

$q^{PP} = \frac{3r[48-c(45r-4)]-32+\Psi}{32(9r-2)} - \frac{10r(1-c)}{25r-12}$, it can be shown that if $c \in [0.25, 0.54), r \geq \underline{r}$, then $q^{FF} - q^{PP} < 0$. If $c \in [0.54, 1), r \geq \underline{r}$, then $q^{FF} - q^{PP} > 0$.

Appendix A2: Proof of Lemma 4

By comparing the SPE values of firms' profits in Universal FD and Universal PD, $\Pi^{FF} - \Pi^{PP} = \{[4rc(9r-8)(27r-4) - 6r\Psi - 3r^2c^2(9r-8)(45r-4) + rc(9r+4)\Psi] * * \frac{[c(288r+64+\Psi)-3c^2r(45r+44)-96]}{8\{32+3r[c(117r-20)-48]+\Psi\}^2}\} - \frac{2r(25r-36)(1-c)^2}{(25r-12)^2}$, it can be shown that that if $c \in [0.25, 0.46), r \geq \underline{r}$, then $\Pi^{FF} - \Pi^{PP} > 0$. If $c \in [0.46, 1), r \geq \underline{r}$, then $\Pi^{FF} - \Pi^{PP} < 0$.

Appendix B: Total Welfare.

Total welfare in the Universal Partial configuration, the Universal Full Delegation, the Coexistence of the two schemes and the No Delegation configuration, respectively is given by the following expressions:

$$\begin{aligned} TW^{FF}(c,r) &= \{17856c^2r - 81c^2r^2[2000 + 9r(225r-572)] + 64r(9r-2)[18r(9r+4) + \Psi - 32] + \\ &\quad +336(\Psi - 64) + 27rc[6784 - 72\Psi + 9r(144r + 5\Psi - 1632)]\} * \\ &\quad * \frac{1}{2304(2-9r)^2} > 0 \end{aligned}$$

$$TW^{PP}(c,r) = \frac{12r(1-c)^2}{25r-12} > 0$$

$$TW^{FP}(c,r) = \frac{2r(1-c)^2\{756r - 84 + r^2[2370r - 2113 + r^2(140r - 999)]\}}{6 + r(8r-25)]^2} > 0$$

$$TW^{ND}(c,r) = \frac{4r(1-c)^2}{9r-4} > 0$$

By comparing the corresponding values of the total welfare, it is easy to check that $TW^{ND} < TW^{FF} < TW^{FP} < TW^{PP}$.

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