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1 Introduction

The contribution of technological change to economic growth is incontestable. Makri et al. (2006) presents empirical evidence revealing that more than 50% of the economic growth during 1945–2002 in the U.S. is accredited to R&D investments within the high-technology sector. Moreover, during 2000-2006, the 10 largest U.S. companies increased their R&D spending by 42%.[1] In addition, numerous empirical studies reveal that innovation in the form of development of new products and cost reducing processes facilitates firms to achieve a competitive advantage in the market in which they operate.[2]

Stylized facts indicate that modern corporations are characterized by separation of ownership and management. In other words, they are characterized by delegation of decisions from owners to managers (e.g., Fama and Jensen 1983, Jensen and Meckling, 1976). Recently, researchers have focussed their attention on the examination of the proper incentives for managers that foster firms' R&D investments. Agency theory, taking into account information asymmetries and moral hazard considerations, suggests that when managers decide on their firms' R&D investments, their remuneration must coincide with the shareholders' objectives, that is, with profit maximization (e.g., Milkovich et al. 1991; Metcalf and Simpson, 2009). Others argue that such a link may induce managers to avoid high-risk R&D investments, which in turn may decrease innovation by firms (Baysinger et al. 1991; Hoskisson et al. 1991; Eisenmann, 2002, Makri et al. 2006).

Yet, the above strand of the literature neglects the strategic interactions that may arise among firms when the latter operate in imperfectly competitive environments. It is important to turn our attention to strategic managerial delegation.[3] In this context, managerial incentives that lead to deviation from strict profit maximization are designed by principals in order to influence the behavior of a rival firm in their favor. The strategic use of managerial incentive contracts has been introduced by Vickers (1985), Fershtman (1985), Fershtman and Judd (1987) and Sklivas (1987) or VFJS henceforth. In these papers, each firm's 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. This particular focus of the VFJS model can be justified on the grounds of empirical studies, which suggest that CEO compensation is positively associated with both profit and sales (Baker et al., 1988; Jensen and Murphy, 1990; Lambert et al., 1991). More specifically, industry level analyses suggest that contracts of this type are widely adopted in the CEO compensation practice in U.S. markets with high R&D investments such as in "new economy" firms (Daroca and Nourayi, 2008) and in the U.S. electric utility industry (Duru and Iyengar, 1999).[4]

This paper aims to investigate the relation between strategic managerial contracts, innovation, firm performance and welfare in a duopolistic market in which owners choose their firms' organizational structure. That is, each firm's owners choose whether they will delegate both R&D investments and market competition decisions to their manager (Full Delegation strategy), or they will delegate only market competition decisions to their manager (Partial Delegation strategy).

More specifically, the present paper attempts to address the following questions. Which are the effects of alternative configurations of organizational structures on the firms' R&D investments and market performance? Which organizational structure will firms' owners select in equilibrium? Do we expect delegation of R&D decisions to be a widespread strategy in real world markets? Which are the welfare effects of each configuration of organizational structures? Are the market and societal incentives aligned?

To address the above questions, we consider a duopolistic homogenous good Cournot industry. We follow the VFJS model, in which the managerial contracts set by firms' owners include sales performance, in order to increase their managers' aggressiveness. Yet, there is one important departure. Owners, besides output decisions, can delegate R&D investment decisions to their managers as well. In particular, we consider a four-stage game with observable actions. In the first stage, firms' owners decide whether to follow a Full Delegation (FD), or a Partial Delegation (PD) strategy. If an owner chooses FD, he also sets the managerial incentive parameter at the same stage. In the second stage, R&D investment levels are decided by the firms' decision making agents (a firm's manager in case of FD or its owner in case of PD). In the third stage, if a firm's owner has chosen PD, he sets the incentive parameter for his manager. In the last stage, managers compete in quantities. In this context, the firms' organizational structures emerge endogenously as a consequence of strategic interactions between competing firms in the market. There are four possible equilibrium configurations of organizational structures in the market: Universal Full Delegation, (FD, FD), in which both firms' owners select the FD strategy; Universal Partial Delegation, (PD, PD), in which both firms' owners select the PD strategy; and the two Asymmetric Delegation configurations, (FD, PD) and (PD, FD), in which one firm's owners choose FD while the rival firm's owners choose PD.[5] It is worth stressing that the above timing of the game reflects that all decisions should be time consistent. For instance, a firm's owners that follow a PD strategy, unless they posses a specific commitment mechanism, cannot credibly commit to a managerial incentive parameter in the first stage, because they will have incentives to revise it after firms' R&D decisions have been taken in the second stage. Still, we also consider the case in which firms' owners can commit to a specific contract type before they choose its respective managerial parameter.

We find that the configuration of organizational structures affects crucially firms' R&D efforts and profitability. In particular, R&D investments are higher under the Universal FD than under the Universal PD configuration. The reason is that under Universal FD firms' managers, who are directed to be more aggressive than strict profit maximization, decide over R&D investments, while R&D decisions are taken by profit maximizing owners under Universal PD. In addition, under the Asymmetric Delegation configuration, the firm that chooses the FD strategy becomes leader in incentives, and thus, invests more in R&D and obtains higher profits than in both the Universal FD and PD configurations; while the opposite holds for the firm that chooses the PD strategy and becomes follower in managerial incentives. Yet, industry R&D expenditures are higher under the Asymmetric configuration than under Universal FD or PD. While the opposite holds for overall industry profits. Moreover, the firms' profits are higher under the Universal FD than under the Universal PD configuration, but only if firms are endowed initially with an efficient technology (i.e., their initial marginal cost is low enough). Otherwise, they are higher under the Universal PD configuration. There is scant empirical evidence on the relation between R&D efforts and delegation schemes which is mixed. Our results partially confirm the findings of a recent strand of the literature that establishes a positive relation between managerial incentives departing from strict profit maximization with firms R&D investments (Makri et al. 2006, Lin et al. 2010). Others support, however, that the alliance between managerial incentives and profit maximization is beneficial for firms R&D investments and market performance (Milkovich, et al. 1991; Metcalf and Simpson, 2009).

Regarding the equilibrium configuration of organizational structures, we find that the Universal PD is never an equilibrium configuration. The Universal FD configuration arises in equilibrium, but only if the initial marginal cost is high enough. Otherwise, the Asymmetric case is an equilibrium configuration. For intermediate values of the initial marginal cost, the Universal FD and the Asymmetric case are both equilibrium configurations. Surprisingly, we show that ex-ante symmetric firms may turn out to be ex-post asymmetric in all aspects, i.e., in their final production technologies, outputs and profitability. This is in line with the empirical evidence, which is though limited and inconclusive. Colombo and Delmastro (2004) suggest that under strategic delegation, some firms' owners tend to delegate only short-run decisions to their managers such as output, while others also delegate long-run decisions such as R&D investments. Note also that, if firms' owners can commit ex ante to the delegation strategies that they will follow ex post, the Universal FD is the unique equilibrium configuration for all values of the initial marginal cost. Thus, we point out that the commitment assumption is not innocuous.

Finally, we show that all configurations of organizational structures with strategic delegation lead to higher welfare than the case in which no firms' owners delegate any decisions to their managers. The reason is that all delegation configurations lead to higher R&D investments, output and consumers' surplus than under no delegation, and the latter compensates for the decrease in the industry's profitability due to higher competition under delegation. Further, under delegation, the Universal FD configuration leads to the lowest total welfare, with the Asymmetric configuration leading to the highest welfare. The latter is mainly due to the fact that, as we said above, industry R&D efforts are higher under the Asymmetric than under the Universal FD or PD configuration. The above results indicate that market and societal incentives are not always aligned. Given that the support of innovation investments is central policy objective in both the U.S., E.U. and China as an instrument for sustainable economic growth (European Commission, 2010; Makri et al. 2006; Lin et al. 2010), exploiting the societal effects of firms R&D investments under strategic choice of organizational structures may turn out to be of great importance for policy makers.

Further, by properly modifying our basic model, we are able to investigate the extent to which our main results remain robust when products are imperfect substitutes or when firms compete in prices. As expected, when products are close enough substitutes under Cournot competition, all our main results remain intact. However, when the products are poor substitutes, the only delegation configuration that arises in equilibrium is the Universal PD. The reason is that low degrees of substitutability among products imply softer competition among firms. This, in turn, reduces the need for high R&D investments and therefore, for the delegation of innovation decisions to more aggressive managers. Further, under price competition, Universal PD arises in equilibrium for all degrees of product substitutability. This is so because in this case, managers are less aggressive than their owners and thus, a PD strategy results in higher cost reducing R&D investments, making the firm more competitive in the market.

Our paper contributes to the organizational structure literature that investigates the optimal remuneration schemes of managers who decide about their firms' R&D investments. The bulk of this literature focuses on agency theory issues that neglect strategic interactions that arise between oligopolistic firms (Makri et al. 2006; Metcalf and Simpson, 2009; Eisenmann, 2002; Milkovich et al. 1991; Baysinger et al. 1991; Hoskisson et al. 1991). However, there is a recent branch of the strategic delegation literature which studies how strategic delegation of decisions from owners to managers affects firm's R&D investments and production decisions. Zhang and Zhang (1997) and Kopel and Riegler (2006; 2008) endogenize the selection between Non-Delegation and Full Delegation, by assuming credible commitment between the rival owners.[6],[7] In this setup, Kopel and Riegler (2008) show that R&D spillovers do not affect firms' owners equilibrium strategy, which is to always choose Full Delegation. Our paper departs from the above literature in four ways. First, we extend the owners' strategy space by also including Partial Delegation as a possible owners' strategy. Second, besides the commitment scenario considered in the literature so far, we also examine the time consistent scenario in which firms' owners are unable to commit to the delegation strategy that they will follow ex-post. Third, we investigate the welfare effects of the alternative organizational structure configurations in the market. Fourth, we examine the effects of product differentiation and price competition to firms' owners incentives to delegate R&D investments decisions to their managers.[8]

Our paper also contributes to the literature that examines the endogenous emergence of asymmetric performance between ex-ante symmetric firms that operate in the same industry (Amir et al., 2010, and Röller and Sinclair-Desgagni, 1996, offer a comprehensive review). Several factors that are responsible for these asymmetries, such as significant entry barriers (Besanko and Doraszelski 2004; Van Long and Soubeyran 2001) and evolutionary forces (Dierickx and Cool,1989), have already been thoroughly analyzed in the literature. Our paper belongs to a strand of the literature that considers differences in organizational structure as a source of such asymmetry (e.g., Bloom and Van Reenen, 2010; Gal-Or, 1997, and Caillaud and Rey, 1994). More specifically, we show that ex ante symmetric firms in an industry may end up being ex post asymmetric in their performance, when firms' organizational structures result from their owners' strategic use of managerial incentives. In particular, firms' owners' choice to remunerate managers with contracts that depart from profit maximization may create asymmetries between rival firms in terms of their R&D expenditures and their performance in the same industry.

The rest of the paper is organized as follows. Section 2 presents the basic model. In Section 3, the different delegation configurations are analyzed and their outcomes are compared. Section 4 investigates the conditions under which alternative delegation configurations emerge in equilibrium. In Section 5, a welfare analysis is conducted. Section 6 discusses the robustness of our main results under a Cournot differentiated goods setup as well as under price competition. Section 7 provides some concluding remarks. All proofs are relegated to the Appendix.

2 The Model

We consider a homogenous good industry in which two firms, denoted by i, $j = 1, 2$, with $i \neq j$, compete in quantities. The inverse demand function for the good is $P(Q) = A - Q$, where $Q = q_1 + q_2$ is the aggregate output. Firms are endowed with constant returns to scale production technologies and their marginal cost is initially equal to C ($C < A$). Firm i, by investing $\frac{r}{2}x_i^2$ in R&D activities, can reduce its marginal cost to $C - x_i$. This quadratic R&D cost specification reflects diminishing returns to R&D expenditures (see e.g. d' Aspremont and Jacquemin, 1988). The parameter r measures the effectiveness of the R&D technology on marginal cost reduction. The higher r is, the higher are the required R&D expenditures for a given marginal cost reduction and the less effective is the R&D technology. Thus, firm i's total cost is: $C_i(.) = (C - x_i)q_i + \frac{r}{2}x_i^2$. To guarantee well-behaved interior solutions under all parameter values we make the following assumption in the sequel:[9]

Assumption 1: $c \equiv \frac{C}{A} \geq 0.3$ and $r \geq 5$.

where c reflects the efficiency of the initial production technology relative to the market size. Assumption 1 requires that the initial marginal cost is not too low relative to the market size; moreover, that the effectiveness of the R&D technology is not too high.

Firm i's profits are:

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

Each firm i 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.[10] Each firm's owner can compensate his manager by offering a "take-it-or-leave-it" incentive contract to him.[11] Under this contract, the incentive structure is assumed to take 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 is given an incentive to maximize:

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

where Π_i and R_i are firm i's profits and revenues respectively,[12] and a_i, $a_i \leq 1$, is the *managerial incentive parameter* which is chosen optimally by firm i's owner so as to maximize his profits. Observe that if $a_i = 1$, manager i's behavior coincides with owner i's objective for strict profit-maximization. If $a_i < 1$, 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 lower the managerial incentive parameter set by owner i is, the higher is the aggressiveness of his manager.

Each firm i's owner can delegate either both the R&D investment and output decisions to his manager (*Full Delegation* strategy, FD), or the output decision alone (*Partial Delegation* strategy, PD). In the latter case, the R&D decision is taken by the owner. To investigate the delegation strategies that firms' owners are expected to follow in equilibrium, we consider a four-stage game with observable actions.[13] In the first stage, firms' owners decide, simultaneously and independently, whether to follow a Full Delegation or a Partial Delegation strategy. If an owner chooses FD, he also sets the managerial incentive parameter at the same stage. Otherwise, he postpones this decision for a later stage when firms' R&D investments have been decided upon and have become common knowledge. In the second stage, firms' decision making agents (a firm's manager in case of FD, or a firm's owner in case of PD) choose, simultaneously and independently, their R&D investment levels. In the third stage, if a firm's owner has chosen a PD strategy, he sets the 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. Figure 1 visualizes the timing of the game.[14]

It is worth stressing that this timing of the game guarantees that all decisions are *time consistent*. Clearly, commitment to a delegation strategy that an owner has incentives to revise later can hardly be justified since it requires the existence of a specific commitment mechanism that firms' owners typically do not possess. For instance, a firm's owner who has decided a PD strategy is unable to commit to a given managerial incentive parameter in the first stage, because it is common knowledge that he will have incentives to revise his decision when R&D investments have been undertaken by firms. In this spirit, it is also clear that firms' R&D decisions will be taken strategically in the second stage in order to influence the choice, in the third stage, of the managerial incentive parameters of the owners who have chosen a PD strategy. It is thus reasonable to focus on time consistent strategies, i.e., strategies that maximize firms' profits at each point in time. The game is solved by employing the Subgame Perfect Nash Equilibrium (SPNE) solution concept.

<<PUT FIGURE 1 HERE>>

3 Delegation Configurations

In this section we examine the alternative delegation configurations that may arise in equilibrium. Due to symmetry, the number of candidate equilibrium configurations reduces to three: *Universal Full Delegation* (FD, FD), *Universal Partial Delegation* (PD, PD), and *Asymmetric Delegation* (FD, PD).

Note first that the "Non-Delegation" case, in which R&D and output decisions are taken by firm i's owner corresponds to the special case of the firm's FD and PD strategies in which the managerial incentive parameter equals 1. Although there is no need for independent treatment of the Non-Delegation configuration, (N, N), we briefly discuss this as a benchmark case.[15] In the Non-Delegation configuration, firms' owners first decide on their R&D expenditures and then choose their outputs. Firm i's reaction function in the output competition stage is, $q_i = R_q^N(q_j) = \frac{A-q_j-(C-x_i)}{2}$. The respective one in the R&D investments stage is, $x_i = R_x^N(x_j) = \frac{4(A-C-x_j)}{9r-8}$. Observe that both firms' outputs and R&D investments are strategic substitutes.

Equilibrium output, R&D investments, and profits are, respectively:

$$q^N = \frac{3r(1-c)A}{9r-4};\ x^N = \frac{4(1-c)A}{9r-4};\ \Pi^N = \frac{r(9r-8)(1-c)^2A^2}{(9r-4)^2} \tag{3}$$

3.1 Universal Full Delegation (FD, FD)

Consider first the Universal FD configuration. In the last stage, given the R&D investments and the managerial incentives, firm i's manager sets output to maximize (2). From the first order condition, the reaction function of manager i is:

$$q_i = R_q^{FD}(q_j) = \frac{A - q_j - a_i(C - x_i)}{2} \tag{4}$$

Observe that manager i perceives $a_i(C - x_i)$ as its firm's marginal production cost. For all $a_i < 1$, the perceived marginal cost is lower than the true marginal cost that the firm's owner faces e.g. in the Non-Delegation case. The lower the managerial incentive parameter that owner i sets, the lower is the marginal cost that manager i perceives and thus the more aggressive manager i becomes in the output setting game. In fact, manager i's reaction function is an outward and parallel shift of the respective owner i's in the Non-Delegation case.

Solving the system of first order conditions, firm i's output is:

$$q_i^{FD}(x_i, x_j, a_i, a_j) = \frac{A - 2a_i(C - x_i) + a_j(C - x_j)}{3} \tag{5}$$

The following observations are in order. First, $\frac{\partial q_i^{FD}}{\partial a_i} < 0$, i.e., the lower the managerial incentive parameter that owner i sets, the higher is the aggressiveness of his manager and the higher is the output level that the latter sets. In contrast, $\frac{\partial q_i^{FD}}{\partial a_j} > 0$, that is, a lower managerial incentive set by the rival owner to his manager discourages manager i to increase its firm's output. Second, $\frac{\partial q_i^{FD}}{\partial x_i} > 0$ and $\frac{\partial q_i^{FD}}{\partial x_j} < 0$. Clearly, as firm i's expenditures on R&D increase, the firm's perceived (and true) marginal cost decreases, and thus its manager sets a higher output level. The opposite holds when the rival firm increases its R&D investments, making thus firm j more efficient in the market. Due to strategic substitutability between firms' quantities, manager i then reduces its firm's output.

In the second stage, each manager i invests in R&D so as to maximize his objective function, which using (4) can be written as: $M_i(x_i, x_j, a_i, a_j) = [q_i^{FD}(\cdot)]^2 - a_i\frac{r}{2}x_i^2$. This objective function reflects the fact that manager i perceives $a_i\frac{r}{2}x_i^2$ as its firm's R&D costs, which are lower than the firm i's true R&D costs as long as $a_i < 1$. Hence, in the Full Delegation case, not only the marginal production cost, but also the R&D costs of the firm are "discounted" by a factor equal to the managerial incentive parameter chosen by its owner. The lower the latter is, the lower are the firm's R&D costs that manager i perceives and thus the more aggressive manager i becomes in the R&D setting game.

>From the first order condition[16], the reaction function of manager i is:

$$x_i = R_x^{FD}(x_j) = \frac{4[A - 2a_iC + a_j(C - x_j)]}{9r - 8a_i} \tag{6}$$

It is easy to see that for all $0 < a_i \leq 1$, $\frac{\partial R_x^{FD}}{\partial x_j} < 0$, that is, rival firms' R&D efforts are strategic substitutes (as in the Non-Delegation case). The higher are the rival firm's R&D investments, the lower are the R&D effort that manager i undertakes. Further, it can be checked that under Assumption 1, when $a_i = a_j$ the manager i's R&D reaction function is always steeper and is an outward shift of the respective owner i's in the Non-Delegation case.

Solving the system of first order conditions, firm i's R&D investments are:

$$x_i^{FD}(a_i, a_j) = \frac{12r(A - 2a_iC + a_jC) - 16a_j(A - a_iC)}{27r^2 - 24r(a_i + a_j) + 16a_ia_j} \tag{7}$$

It can be seen that under Assumption 1, $\frac{\partial x_i^{FD}}{\partial a_i} < 0$ and $\frac{\partial x_i^{FD}}{\partial a_j} > 0$.[17] Clearly, a more aggressive manager i (lower a_i) chooses a higher R&D effort because he perceives his firm's R&D costs to be lower. Moreover, the higher is a_j, and thus the less aggressive is manager j, the higher are the incentives of manager i to spend on R&D because in this case, its firm is expected to produce a relatively higher output. This is the well-known in the literature output effect (see e.g., Bester and Petrakis, 1993). The above reveal that owners may strategically choose the incentive parameters for their managers in the first stage in order each to influence his rival manager choice of R&D effort. In fact, by directing its manager towards a more aggressive behavior, owner i may discourage manager j from spending on his firm's R&D activities.

In the first stage, each owner i chooses a_i so as to maximize profits $\Pi_i^{FD}(a_i, a_j)$, which can be obtained by substituting (7) into (5) and (1). From the first order condition, the reaction function of owner i is (where $c = \frac{C}{A}$):

$$a_i = R_a^{FD}(a_j) = \frac{(3r - 4a_j)[3r(16 + 9r) - 32a_j] - 3cr[128a_j^2 - 300ra_j + 27r^2(6 - a_j)]}{4(3r - 2a_j)\{6(3r - 4a_j) - c[3r(4 + 9r) - 2a_j(4 + 27r)]\}} \tag{8}$$

It can be checked that under Assumption 1, $\frac{\partial R_a^{FD}}{\partial a_j} < 0$,[18] i.e., managerial incentives are strategic substitutes. As owner j directs his manager towards a relatively less aggressive behavior, the rival owner manipulates his manager's behavior in the opposite direction in order to push him towards higher R&D effort and output and in this way, to increase firm i's market share and profits.

Exploiting symmetry, the equilibrium managerial incentive parameter is:

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

where $\Psi = \sqrt{-512(9r - 2) - 96rc(9r - 28)(9r - 2) + 9r^2c^2[784 + 9r(225r - 424)]}$.

It can be checked that under Assumption 1, $0 < a^{FD} \leq 1$. Note that $\frac{\partial a^{FD}}{\partial r} > 0$ and $\frac{\partial a^{FD}}{\partial c} > 0$. The higher are the firms' marginal production and R&D costs, the more reluctant are their owners to direct their managers to more aggressive behavior. This is so because the ensuing profits from delegation are lower in this case.

>From (9), we get respectively each firm's equilibrium R&D investments, output and profits:

$$x^{FD} = x_n^{FD} A; \quad q^{FD} = \frac{3r}{4} x_n^{FD} A; \quad \Pi^{FD} = \frac{r x_n^{FD}}{8} [6(1-c) - (9r-2) x_n^{FD}] A^2 \tag{10}$$

where

$$x_n^{FD} = \frac{16(9r-2) - 3cr(45r-4) + \Psi}{24r(9r-2)} > 0.$$

3.2 Universal Partial Delegation (PD, PD)

We consider next the Universal Partial Delegation configuration. The last stage is the same as under Universal Full Delegation and the equilibrium outputs are given by (5), i.e., $q_i^{PD}(x_i, x_j, a_i, a_j) = q_i^{FD}(x_i, x_j, a_i, a_j)$.

In the third stage, each owner i chooses a_i so as to maximize profits, which after some manipulations can be written as: $\Pi_i(a_i, a_j, x_i, x_j) = [q_i^{PD}(\cdot)]^2 - (1-a_i)(C-x_i) q_i^{PD}(\cdot) - \frac{r}{2} x_i^2$. From the first order condition[19], the reaction function of owner i is:

$$a_i = R_a^{PD}(a_j) = \frac{6C - A - 6x_i - a_j(C - x_j)}{4(C - x_i)} \tag{11}$$

Note that $\frac{\partial R_a^{PD}}{\partial a_j} < 0$, that is, as in the Universal Full Delegation case, managerial incentives are strategic substitutes here too. Reacting to owner j who directs his manager towards a less aggressive behavior, owner i makes his manager more aggressive so that the latter increases his firm's output and profits in the market.

Solving the system of first order conditions, we obtain the equilibrium managerial incentive parameters,

$$a_i^{PD}(x_i, x_j) = \frac{6C - A - 8x_i + 2x_j}{5(C - x_i)} \tag{12}$$

Observe that $\frac{\partial a_i^{PD}}{\partial x_i} < 0$ and $\frac{\partial a_i^{PD}}{\partial x_j} > 0$. When firm i's R&D investments increase, and thus, its marginal cost decreases, the owner i has incentives to direct his manager to a more aggressive behavior in the output setting stage. This is so because a more efficient firm has more to gain by expanding its own output and thus forcing its rival to drastically reduce its output. For a similar reason, when the rival firm j becomes more efficient (higher x_j), firm i's output expansion is not too rentable and thus owner i directs his manager to a less aggressive behavior. This discussion reveals that owners may strategically spend on R&D in stage two in order to influence the choices of managerial incentive parameters in the following stage three. Indeed, owner i may strategically spend more on R&D in order to prevent his rival owner from making his manager too aggressive.

In the second stage, owners simultaneously set their R&D investments so as to maximize their profits, which after some manipulations can be written as: $\Pi_i(x_i, x_j) = \frac{1}{2}[q_i^{PD}(x_i, x_j)]^2 - \frac{r}{2}x_i^2$, with $q_i^{PD}(x_i, x_j) = \frac{2}{5}(A - C + 3x_i - 2x_j)$. >From the first order condition[20], the reaction function of owner i is:

$$x_i = R_x^{PD}(x_j) = \frac{12(A - C - 2x_j)}{25r - 36} \tag{13}$$

Note that as above, R&D investments are strategic substitutes ($\frac{\partial R_x^{PD}}{\partial x_j} < 0$) here too. By exploiting symmetry, we obtain the equilibrium R&D investments ($c = \frac{C}{A}$):

$$x^{PD} = \frac{12(1 - c)A}{25r - 12} \tag{14}$$

Finally, each firm's equilibrium managerial incentive parameter, output, and profits are, respectively:

$$a^{PD} = \frac{5(6c - 1)r - 12}{25cr - 12}; \quad q^{PD} = \frac{5r}{6}x^{PD}; \; \Pi^{PD} = \frac{2r(25r - 36)(1 - c)^2 A^2}{(25r - 12)^2} \tag{15}$$

It can be checked that $0 \leq a^{PD} \leq 1$ in the permissible parameter region. Note that $\frac{\partial a^{PD}}{\partial r} > 0$ and $\frac{\partial a^{PD}}{\partial c} > 0$. As in the case of Universal Full Delegation, here too owners are more reluctant to make their managers aggressive when their production and R&D costs become higher.

At this point, it is interesting to investigate how the alternative symmetric delegation configurations affect the firms' managerial incentive parameters, R&D investments, output and profits. The following Proposition summarizes:

Proposition 1 *(i) Managers are always directed by owners to be less aggressive under Universal Full Delegation than under Universal Partial Delegation ($a^{FD} > a^{PD}$).*

(ii) Firms always invest more in R&D under Universal Full Delegation than under Universal Partial Delegation ($x^{FD} > x^{PD}$).

(iii) Firms produce lower output under Universal Full Delegation than under Universal Partial Delegation ($q^{FD} < q^{PD}$) if and only if $c < \widehat{c}_q(r) \equiv \frac{3(112+40r+75r^2)}{4r(196+75r)}$, with $\frac{d\widehat{c}_q}{dr} > 0$, and $\widehat{c}_q(5) = 0.5745$ and $\lim_{r\to\infty} \widehat{c}_q(r) = 0.75$.

(iv) Firms profits are higher under Universal Full Delegation than under Universal Partial Delegation ($\Pi^{FD} > \Pi^{PD}$) if and only if $c < \widehat{c}_\Pi(r)$ where $\widehat{c}_\Pi(r) \approx 0.45$.[21]

The intuition behind Proposition 1(i) rests on two facts. First, under Universal FD both R&D and output costs are "discounted" according to the managerial incentive parameter, while only output costs are discounted under Universal PD. Thus, in principle, the FD configuration may be more costly for the owners rather than the PD one. Second, managers under Universal FD have more degrees of freedom to act strategically (i.e., in both the R&D and output setting stages) than under Universal PD. Due to the above, owners have lower incentives to make their managers aggressive under Universal FD.

The rational behind Proposition 1(ii) is obvious. Under Universal FD firms' managers decide over R&D investments, while R&D decisions are taken by profit maximizing owners under Universal PD. As managers are directed to be more aggressive than strict profit maximization, R&D investments turn out to be higher under Universal FD rather than under Universal PD.

Regarding Proposition 1(iii), the above analysis reveals that there are two opposite effects on output. First, under Universal FD firms invest more on R&D rather than under Universal PD (Proposition 1(ii)), and this tends to lead to higher output in the former rather than in the latter case. Second, under Universal FD owners set a lower level of aggressiveness for their managers, leading thus to lower output, rather than under Universal PD (Proposition 1(i)). If $c > \widehat{c}_q(r)$, the first positive effect dominates the second negative effect and thus, the output is higher under Universal FD. This is so because a high initial marginal cost induces higher R&D

expenditures, while, at the same time, it makes firms' owners less keen to direct their managers to a more aggressive behavior. Thus, for $c > \widehat{c}_q(r)$, the positive effect is intensified, while the negative effect is attenuated. The opposite is true for low values of the initial marginal cost ($c < \widehat{c}_q(r)$) and thus output is higher under Universal PD in this case.

The intuition behind Proposition 1(iv) is rather straightforward. From Proposition 1(ii), we know that R&D expenditures are always higher under Universal FD rather than under Universal PD. Thus, a necessary condition for the profits to be higher in the former case is that market competition is softer relative to the latter case. This occurs only if the initial marginal cost is low enough, in which case output is lower under Universal FD rather than under Universal PD (Proposition 1(iii)). In fact, only if c is quite low, i.e., $c < \widehat{c}_\Pi(r) < \widehat{c}_q(r)$, the softer market competition effect overturns the higher R&D expenditures effect and profits are higher under Universal FD. The opposite occurs for higher values of the initial marginal cost, in which case Universal PD leads to higher firms' profits rather than Universal FD.

3.3 Asymmetric Delegation Configuration (FD, PD)

Next, we turn to the Asymmetric Delegation configuration case. In this case, without loss of generality, we assume that owner 1 follows the Full Delegation strategy, while his rival owner 2 chooses the Partial Delegation strategy. The last stage of the game is the same as under Universal Full Delegation and the equilibrium outputs are given by (5): $q_i^A(x_i, x_j, a_i, a_j) = q_i^{FD}(x_i, x_j, a_i, a_j)$.

In the third stage, owner 2 chooses a_2 so as to maximize profits that, as above, are given by $\Pi_2(x_1, x_2, a_1, a_2) = [q_2^A(\cdot)]^2 - (1 - a_2)(C - x_2)q_2^A(\cdot) - \frac{r}{2}x_2^2$. From the first order condition, the managerial incentive parameter of owner 2 is:

$$a_2^A(x_1, x_2, a_1) = \frac{6C - A - 6x_2 - a_1(C - x_1)}{4(C - x_2)} \tag{16}$$

Observe that owner 2, who is follower in setting the managerial incentives, optimally reacts to a more aggressive behavior chosen by the leader owner 1 for his manager, by directing his manager to a less aggressive behavior ($\frac{\partial a_2^A}{\partial a_1} < 0$). The latter reveals that owner 1 may strategically choose his manager's incentives in stage one, in order to force his rival owner to direct his manager to a less aggressive behavior later on. Further, as in the Universal Partial Delegation case, an increase in own R&D investments results in a more aggressive behavior for firm 2's manager ($\frac{\partial a_2^A}{\partial x_2} < 0$), while the opposite holds when firm 1's R&D investments increase ($\frac{\partial a_2^A}{\partial x_1} > 0$).

In the second stage, manager 1 and owner 2 choose R&D investment levels, so as the former to maximize his objective and the latter its firm's profits, which are respectively, $M_1 = [q_1(x_1, x_2, a_1, a_2^A(\cdot))]^2 - a_1 \frac{r}{2} x_1^2$ and $\Pi_2 = \frac{1}{2}[q_2^A(x_1, x_2, a_1, a_2^A(\cdot))]^2 - \frac{r}{2} x_2^2$.

$>$From the first order conditions, the reaction functions of manager 1 and owner 2 are, respectively:

$$x_1 = R_x^A(x_2) = \frac{3[A + (2 - 3a_1)C - 2x_2]}{8r - 9a_1}$$

$$x_2 = R_x^A(x_1) = \frac{A - 2C + a_1(C - x_1)}{2(r - 1)} \tag{17}$$

Note that R&D investments are again strategic substitutes, i.e., $\frac{\partial R_x^A(x_i)}{\partial x_i} < 0$. Moreover, an increase in manager 1's aggressiveness set by his owner in the first stage (lower a_1) has a negative impact on the rival firm 2's R&D investments and a positive impact on own R&D investments. Clearly, a more aggressive manager 1 will increase its firm's R&D investments. On the other hand, the rival owner 2 will decrease R&D expenditures since he expects a significant output contraction for his firm, that would result from the more aggressive manager 1's output setting in the last stage.

Solving the first order conditions, firms' R&D investments are:

$$x_1^A(a_1) = \frac{3A(r - 2) + 6Cr - 3a_1 C(3r - 2)}{8r(r - 1) - 3a_1(3r - 2)} \tag{18}$$

$$x_2^A(a_1) = \frac{4Ar - 8Cr + a_1[-6A + C(6 + 4r)]}{8r(r - 1) - 3a_1(3r - 2)} \tag{19}$$

It can be checked that $\frac{\partial x_1^A}{\partial a_1} < 0$, while $\frac{\partial x_2^A}{\partial a_1} > 0$. This is in line with our discussion above and confirms that owner 1 may strategically choose his managers' incentives in order to reduce its rival's manager R&D spending.

In the first stage, owner 1 chooses a_1 so as to maximize his profits which can be written as: $\Pi_2 = \frac{1}{2}[q_2^A(x_1^A(\cdot), x_2^A(\cdot), a_1, a_2^A(\cdot))]^2 - \frac{r}{2}[x_2^A(\cdot)]^2$. From the first order condition, we obtain the equilibrium incentive parameter for manager 1:

$$a_1^A = \frac{(r-2)[r(8r+9]-6]-2cr[r(16r-49+22]}{(3r-2)\{6(r-2)-c[r(8r-19)-6]\}} \tag{20}$$

Substituting (20) into (18) and (19) and these into (16), we get the equilibrium incentive parameter for manager 2:

$$a_2^A = \frac{(r+2)[6+r(4r-17)]-4cr[r(7r-25)+10]}{2[6+r(4r-17)]-cr[(24r-83)r+34]} \tag{21}$$

It can be checked that $0 < a_2^A < 1$ and $a_1^A < a_2^A$. Interestingly, a_1^A is not always positive. In fact, $a_1^A \leq 0$ if and only if $c \leq \widetilde{c}$ where $\widetilde{c} = \frac{(r-2)[r(8r+9)-6]}{2r[r(16r-49)+22]}$, with $\frac{d\widetilde{c}}{dr} < 0$ and $\widetilde{c}(5) = 0.4051$. The leader in setting managerial incentives owner 1 directs his manager to a more aggressive behavior than the follower owner 2. In fact, when the initial marginal cost is low enough, the leader owner 1, instead of rewarding his manager for profits, he penalizes him by overcompensating him for firm's sales. Further, as above, $\frac{\partial a_i^A}{\partial c} > 0$, $i = 1, 2$. On the other hand, $\frac{\partial a_1^A}{\partial r} > 0$, while $\frac{\partial a_2^A}{\partial r} < 0$. Intuitively, as the R&D technology becomes more effective (lower r), the leader in setting managerial incentives owner 1 directs his manager to be more aggressive. Then, as stated above, the follower owner 2 reacts by setting a less aggressive behavior for his manager.

Finally, each firm's equilibrium R&D investments, output, and profits are:

$$x_1^A = \frac{6(r-2)(1-c)A}{r(8r-25)+6};\ x_2^A = \frac{2(1-c)(4r^2-17r+6)}{(3r-2)[r(8r-25)+6)};\ q_1^A = \frac{2r}{3}x_1^A;\ q_2^A = rx_2^A \tag{22}$$

$$\Pi_1^A = \frac{2r(r-2)^2(1-c)^2A^2}{(3r-2)[r(8r-25)+6]};\ \Pi_2^A = \frac{2r(r-1)(1-c)^2[r(4r-17)+6]^2A^2}{(3r-2)^2[r(8r-25)+6]^2} \tag{23}$$

It can easily be checked that firm 1's R&D investments, output and profits are higher than the respective ones of firm 2, i.e., $x_1^A > x_2^A$, $q_1^A > q_2^A$, and $\Pi_1^A > \Pi_2^A$. The leader in setting managerial incentives owner 1 directs his manager to a more aggressive behavior and thus his manager chooses both R&D effort and output higher than those of firm 2. As a result, firm 1's profits are higher than those of firm 2.

By comparing the equilibrium values of R&D investments, managerial incentive parameters, output and profits in the Asymmetric Delegation configuration with the symmetric ones - Universal FD and Universal PD - the following Proposition derives.

Proposition 2 *Comparing the Asymmetric Delegation configuration with the Universal Full Delegation and the Universal Partial Delegation configurations, the following inequalities hold:*

(i) $a_1^A < a^{PD} < a^{FD} < a_2^A$

(ii) $x_1^A > x^{FD} > x^{PD} > x_2^A$

(iii) $q_1^A > \max[q^{FD}, q^{PD}]$ *and* $q_2^A < \min[q^{FD}, q^{PD}]$

(iv) $\Pi_1^A > \max[\Pi^{FD}, \Pi^{PD}]$ *and* $\Pi_2^A < \min[\Pi^{FD}, \Pi^{PD}]$

(v) $X^A = x_1^A + x_2^A > X^{FD} = 2x^{FD}$

(vi) $Q^A = q_1^A + q_2^A > \max[Q^{FD}, Q^{PD}]$, *with* $Q^k = 2q^k$, $k = FD, PD$

(vii) $T\Pi^A = \Pi_1^A + \Pi_2^A < \min[T\Pi^{FD}, T\Pi^{PD}]$, *with* $T\Pi^k = 2\Pi^k$, $k = FD, PD$

The intuition behind Proposition 2 goes as follows. The leader in setting managerial incentives, owner 1, directs his manager to a more aggressive behavior than under any of the two symmetric delegation configurations. Thus, manager 1 chooses relatively higher levels of R&D effort and output. In contrast, and as discussed above, the follower in setting managerial incentives owner 2 reacts by choosing to invest less in R&D and by setting a lower level of aggressiveness for his manager than under Universal FD or PD; manager 2 then chooses a relatively lower level of output. As a consequence, the leader in incentives firm 1 "dominates" the market and earns higher profits than any firm under the two symmetric delegation configurations, while the opposite is true for the follower in incentives firm 2.

Furthermore, it is worth noting that the level of managerial aggressiveness set by owner 1 is so high (remember that a_1^A could even be negative) that results in higher industry R&D expenditures and industry output, yet lower industry profitability, in the Asymmetric case, as compared with both symmetric delegation configurations.

Finally, one can easily check that all delegation configurations lead to higher industry R&D investments and output than under the benchmark case of non-delegation.[22] Then, due to a more intense competition under delegation, industry profitability is lower than under non-delegation. In fact, even the leader in managerial incentives firm 1 obtains lower profits than any firm in the non-delegation case.

4 Equilibrium Delegation Configurations

The literature so far has considered only symmetric delegation configurations. More importantly, it has assumed that rival owners are able to announce and commit to the delegation strategies that they will follow in the future. In this literature, all firms choose either the Full Delegation strategy or the Partial Delegation strategy. This is however in contrast to the empirical evidence (Colombo and Delmastro, 2004), that indicates that these two delegation strategies often coexist in the same industry. As we demonstrate below, the commitment assumption is not innocuous. By relaxing this assumption and allowing only for time consistent firms' strategies, the Asymmetric Delegation configuration may arise in equilibrium under very plausible conditions.

4.1 Equilibrium under commitment

Following the bulk of the literature, in this subsection we investigate the equilibrium delegation configurations under the assumption that firms' owners can commit to their delegation strategies. To do so, we add a new stage, stage zero, in the game in which owners commit over the strategy that they will follow in the future. In stage zero, owners, simultaneously and independently, select between an FD strategy and a PD strategy. Table 1 provides the owners' profits in the ensuing 2×2 matrix game in stage zero.

<<PUT TABLE 1 HERE>>

An immediate consequence of Proposition 2(iv) is that the Full Delegation strategy strictly dominates the Partial Delegation strategy. In particular, if owner i chooses the PD strategy, then the best response of the rival firm's owner is to choose the FD strategy ($\Pi_1^A > \Pi^{PD}$). In this way, he becomes leader in setting managerial incentives and increases his firm's market share and profits. At the same time, if owner i chooses the FD strategy, then the best response of the rival owner is to choose the FD strategy as well. Otherwise, the latter becomes follower in setting managerial incentives and obtains relatively low profits ($\Pi_2^A < \Pi^{FD}$). Therefore, the unique equilibrium of the commitment game is (FD, FD). The following Proposition summarizes:

Proposition 3 *If firms' owners can commit ex ante over the delegation strategies that will follow ex post, Universal Full Delegation is the unique equilibrium configuration.*

This finding is in line with empirical evidence revealing that contracts that combine own profits and sales are widely adopted in firms with high R&D investments (Daroca and Nourayi, 2008 and Duru and Iyengar, 1999). In addition, it confirms the main result of Zhang and Zhang (1997) and Kopel and Riegler (2006; 2008) in case that firms' owners have an additional strategy, the PD strategy, in their disposition.

4.2 Equilibrium under non-commitment

So far our analysis has followed the bulk of the received literature in the field of strategic managerial incentive contracts, by assuming that firms' owners can commit over the types of contracts that they choose to compensate their managers. In what follows, we examine the delegation configurations that emerge in equilibrium when firms' owners are unable to commit ex-ante to the delegation strategies that they will follow ex-post. We thus relax the assumption of the previous subsection that there is a stage zero in the game in which owners can commit to a given strategy. As is standard, we first propose a candidate equilibrium configuration, and then check whether it survives all possible deviations. The three candidate equilibrium delegation configurations analyzed in Section 3 are tested against all possible deviations in the next three subsections.

4.2.1 Universal Full Delegation Configuration.

Universal Full Delegation (FD, FD) is an equilibrium configuration if and only if no owner has incentives to unilaterally deviate from the FD strategy in the first stage and switch to the PD strategy. Without loss of generality, let owner 1 stick to FD and optimally set the incentive parameter a^{FD} for his manager. Does owner 2 have incentives to postpone the managerial incentive parameter choice for a later stage and thus keep for himself the firm 2's R&D decision? In this case, the deviation game unravels as follows. Given owner 1's choice of a^{FD} in the first stage, R&D decisions are taken by manager 1 and owner 2 in the second stage. Then owner 2 sets the incentive parameter of his manager in stage three and finally in the last stage firms' managers compete in quantities.

It is easy to see that the equilibrium of the deviation game coincides with that of the Asymmetric Delegation configuration, with the only exception that in the first stage owner 1 sets $a_1 = a^{FD}$. By substituting $a_1 = a^{FD}$ into (18) and (19), and using (16), (4) and (1), the deviant firm 2's profits are:

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

By comparing the deviation profits with the profits that result in the Universal FD configuration, we obtain that $\Pi_2^d > \Pi^{FD}$ if and only if $c < \overline{c}_{FD}(r)$, where $\overline{c}_{FD}(.)$ is initially (slightly) decreasing and then increasing in r, and $\overline{c}_{FD}(5) = 0.3574$ (see Figure 2). Therefore, for all

$c \geq \bar{c}_{FD}(r)$, Universal Full Delegation is an equilibrium configuration. In Figure 2, this is the region to the right of the $\bar{c}_{FD}$ curve.

The intuition goes as follows. If the initial marginal cost is relatively high, a firm's owner has no incentives to switch to a PD strategy, because by non-delegating R&D effort to an aggressive manager, his firm's R&D expenditures will be seen reduced. In turn, his manager will be put in a relatively disadvantageous position in the output setting stage, not only due to the firm's higher marginal cost, but also because the follower in setting managerial incentives owner will typically direct his manager to a relatively less aggressive behavior. In fact, it can be checked that $a_2^d > a^{FD}$ for most of the parameter values such that $c \geq \bar{c}_{FD}$. In contrast, if the initial marginal cost is low enough, the deviant owner will typically direct his manager to a more aggressive behavior in the output setting game. The latter positive effect more than compensates the negative effect due to the relatively higher marginal cost of the deviant firm, resulting from its lower R&D expenditures. Note also that the deviant owner saves on R&D costs too. The overall effect for the deviant owner turns out to be positive. Thus, (FD, FD) cannot be sustained in equilibrium for low enough c.

4.2.2 Universal Partial Delegation Configuration

Universal Partial Delegation (PD, PD) is an equilibrium configuration if and only if no owner has incentives to switch to an FD strategy and set the incentive parameter for his manager in the first stage. Without loss of generality, let owner 1 stick to the PD strategy and thus take no action in the first stage of the game. Does owner 1 has incentives to set the managerial incentive in the first stage and delegate both R&D and output decisions to his manager? In this case, the deviation game unravels as follows. In the first stage, owner 1 sets a_1. In stage two, manager 1 and owner 2 chose their firms' R&D expenditures. In the third stage, owner 2 sets a_2, and in the final stage managers engage in output competition. It is worth stressing that the deviation game replicates the Asymmetric Delegation game. This is so because owner 2 knows the whole history of actions (a_1, x_1, x_2) while setting a_2 and, moreover, owner 1 anticipates that owner 2 will optimally react to this history.

An immediate consequence of Proposition 2(iv) is that the deviant owner 1's profits are always higher than his equilibrium profits under Universal Partial Delegation, i.e., $\Pi_1^d = \Pi_1^A > \Pi^{PD}$. Clearly, the reasoning is the same as that explained in Section 3. Hence, (PD, PD) can never be sustained as an equilibrium configuration.

4.2.3 Asymmetric Delegation Configuration

In order for the Asymmetric Delegation to be an equilibrium configuration it has to prove immune to two possible deviations. First, owner 1 may deviate from the FD to the PD strategy. And second, owner 2 may deviate from the PD to the FD strategy.

The first deviation game unravels as follows. In stage one, there is no action. In the second stage, owners choose their firms' R&D expenditures, while in stage three they choose their managers' incentive parameters. Finally, managers engage in output competition. It is easy to see that this deviation game is identical to the Universal Partial Delegation game. Clearly, since owner 1 takes no action in stage one, it becomes common knowledge that he will set the managerial incentive parameter in the third stage of the game. Proposition 2(iv) implies that owner 1 has no incentives to deviate because the deviant profits are Π^{PD}, which are always lower than his profits Π_1^A in the Asymmetric Delegation game.

In the second deviation game, owner 1 sticks to the FD strategy and sets $a_1 = a_1^A$, since he expects his rival owner to follow the PD strategy and postpone the managerial incentive selection for a later stage. However, the deviant owner 2 sets instead the incentive parameter for his manager in the first stage, optimally responding to a_1^A. In stage two of the deviation game, managers set their firms' R&D expenditures, and in the last stage they set outputs. Observe that this deviation game coincides with the Universal Full Delegation game, with the only exception that owner 1 chooses a_1^A instead of a^{FD}. The optimal response of owner 2 is given by (8), that is, $a_2^d = R_a^{FD}(a_1^A)$. Plugging a_1^A and a_2^d into $\Pi_2^{FD}(a_1, a_2)$ we obtain the deviant firm 2's profits Π_2^d.[23]

By comparing Π_2^d with the firm 2's profits in the Asymmetric Delegation game, it can be checked that $\Pi_2^d > \Pi_2^A$ if and only if $c > \overline{c}_A(r)$, with $\frac{\partial \overline{c}_A}{\partial r} < 0$ and $\overline{c}_A(5) = 0.4377$ (see Figure

2). Therefore, for all $c \leq \overline{c}_A(r)$, Asymmetric Delegation is an equilibrium configuration. In Figure 2, this is the region to the left of the $\overline{c}_A$ curve. The intuition goes as follows. We know that in the Asymmetric Delegation case, owner 1 directs his manager to be too aggressive, i.e., a_1^A is quite low and could be negative for low values of c. As managerial incentive parameters are strategic substitutes, the deviant owner 2 will respond by directing his manager to be less aggressive, in particular when the initial marginal cost is relatively low. As a consequence, the outcome of the Universal Full Delegation game will be quite biased, both in terms of R&D efforts and outputs, against the deviant owner 2. Hence, his deviation profits will be low and there will be no incentives to deviate from the PD to the FD strategy. The opposite reasoning applies when the initial marginal cost is relatively high, in which case there are always deviation incentives for owner 2.

The following Proposition summarizes our results:

Proposition 4 *(i) If $c \geq \overline{c}_{FD}(r)$, then the Universal Full Delegation is an equilibrium configuration.*

(ii) If $c \leq \overline{c}_A(r)$ the Asymmetric Delegation is an equilibrium configuration.

(iii) The Universal Partial Delegation is never an equilibrium configuration.

Proposition 4 is in line with the empirical evidence provided by Colombo and Delmastro (2004) that often shows coexistence of the two delegation strategies in equilibrium.

<<PUT FIGURE 2 HERE>>

Note that $\overline{c}_{FD}(r) < \overline{c}_A(r)$ for all r. Then, for $\overline{c}_{FD}(r) < c < \overline{c}_A(r)$, there are three equilibrium configurations, the two Asymmetric Delegation ones and the Universal Full Delegation, which cannot be Pareto ranked. Moreover, for $c < \overline{c}_{FD}(r)$, besides the two Asymmetric Delegation configurations, there is also an equilibrium in mixed strategies, the analysis of which is beyond the scope of this paper.

5 Welfare Analysis

In this section, we examine the welfare implications of the alternative delegation configurations and also compare with the total welfare in the benchmark Non-Delegation case.

Total welfare is defined as:

$$TW^m = CS^m + T\Pi^m, \text{ with } m = PD, FD, A, N \tag{24}$$

where $CS^m = \frac{1}{2}(Q^m)^2$ is the consumers' surplus and $T\Pi^m$ the industry profits. Using the equilibrium results obtained above, the total welfare corresponding to all scenarios are included in Appendix B. Our results from the total welfare comparison are included in the following Proposition:

Proposition 5 *Under delegation, Universal Full Delegation leads to the lowest total welfare, while Asymmetric Delegation Configuration leads to the highest welfare, with the Universal Partial Delegation lying in between. Total welfare is always lower under Non-Delegation than under any Delegation configuration:* $TW^N < TW^{FD} < TW^{PD} < TW^A$.

Proposition 5 indicates that strategic delegation improves welfare relative to the benchmark case of Non-Delegation. This is so because delegation intensifies market competition, and thus, consumer surplus is always higher than under Non-Delegation. The increase in consumer surplus more than compensates for the decrease in firms' profits due to stronger competition, and thus, total welfare is higher than in the benchmark non-delegation case.

Moreover, Proposition 5 informs us that the Asymmetric Delegation configuration leads to the highest welfare. This is an immediate consequence of Proposition 2. As we saw, industry output is higher under Asymmetric Delegation than under any of the two symmetric delegation configurations (Proposition 2(v)). As a result, consumer surplus is also higher in this case. The increase in consumer surplus more than compensates for the decrease in the profitability of the firms which according to Proposition 2(vi), is always lower under the Asymmetric rather than under any symmetric delegation configuration.

Further, according to Proposition 5, the Universal Partial Delegation configuration leads to higher welfare than the Universal Full Delegation one. From Proposition 1(iii) we know that for low values of initial marginal cost, industry output and thus consumer surplus is higher under Universal PD rather than under Universal FD. Although profits are sometimes lower under Universal PD in this case (Proposition 1(iv)), the decrease in industry profitability is more than compensated by the consumer surplus increase and total welfare is higher under Universal PD rather than under Universal FD. The reverse reasoning applies for high values of c and again profits turn out to be higher under Universal PD.

Finally, it follows from Proposition 5 that market and social incentives are not always aligned. The Asymmetric Delegation configuration which is socially preferable emerges in equilibrium but only if the initial marginal cost is relatively low. In contrast, if the initial marginal cost is high enough, the Universal Full Delegation that emerges in equilibrium is the least preferable delegation configuration from the social point of view.

6 Discussion-Extensions

In this section we consider a number of modifications of the basic model in order to briefly discuss the robustness of our main results.[24]

6.1 Differentiated Goods

The first modification builds upon the framework of Section 2 with one important departure. In order to examine the effects of product substitutability, we assume that firms produce differentiated products. In particular, we assume that each firm faces the following (inverse) demand function: $p_i = A - q_i - \gamma q_j$, $i, j = 1, 2$; $i \neq j$, where $\gamma \in [0, 1]$ is the degree of product substitutability. Namely, a higher γ implies higher product substitutability and thus, a more intense market competition among competing brands. For tractability, and without loss of generality, we assume that $r = 5$.

As expected, for relatively high values of γ, $\gamma > \tilde{\gamma} = 0.545815$, we reconfirm all our results of the basic model. More specifically, when firms' owners can commit to the delegation strategy that they will follow, then Universal FD is the only equilibrium configuration. Further, when there is no ex ante commitment, then (i) Universal PD is never an equilibrium configuration, (ii) Universal FD is an equilibrium configuration only if products are close enough substitutes and the initial marginal cost is sufficiently high, i.e., $c > \overline{c}_F(\gamma)$, where $\frac{d\overline{c}_F}{d\gamma} < 0$ and $\overline{c}_F(1) = 0.3574$, and (iii) Asymmetric delegation configuration is an equilibrium for all $\gamma > \tilde{\gamma}$ only if the initially marginal cost is sufficiently low, i.e., $c < \overline{c}_A(\gamma)$, where $\frac{d\overline{c}_A}{d\gamma} < 0$ and $\overline{c}_A(1) = 0.4377$. The intuition behind these results is along the lines of that for the homogenous good case. Yet, for relatively low substitutability among brands ($\gamma < \tilde{\gamma}$), the only delegation configuration that arises in equilibrium is Universal PD, independently whether firms' owners can commit, or not, to specific delegation strategies. The rational behind this result is that since lower γ implies lower intensity of competition among brands, the incentives for firms to engage in fiercer R&D competition, via an FD strategy, is seen reduced. Hence, for lower values of γ, firms choose the PD strategy in equilibrium. Finally, our findings indicate that, as in the case of homogenous goods, here too market and societal incentives are not always aligned. For instance, for low values of γ, total welfare is the highest under Universal FD, yet the market leads to Universal PD in equilibrium.

6.2 Price competition

We consider next what happens when firms compete in prices, instead of quantities. As above, each firm produces one brand of a differentiated good and faces the following demand function: $q_i = \frac{A(1-\gamma)-p_i+\gamma p_j}{1-\gamma^2}$ $i, j = 1, 2$; $i \neq j$, where γ is the degree of product substitutability.[25] In this context, we reconfirm the VFJS prediction that, in contrast to quantity competition, firms' owners under price competition set managerial incentives that correspond to penalizing sales; equivalently, they optimally choose $a_i > 1$ under all circumstances (see (2)). Further, our findings indicate that Universal Partial Delegation is the unique equilibrium delegation configuration, independently of whether firms' goods are poor or close substitutes or whether firms' owners are able to commit, or not, to their delegation strategies. The intuition behind this result is that since owners are now more aggressive than their managers (recall that, $a_i > 1$), choosing the PD strategy results in higher cost reducing R&D investments. This allows firms to become more competitive in the market, and thus earn higher profits than when choosing the FD strategy. Yet, total welfare is higher when there is no delegation of any decision. Once more, market and societal incentives are not aligned under price competition.

7 Conclusion

We have investigated the relation between strategic managerial incentives, innovation, firm performance and welfare in a duopolistic market in which firms' organizational structures are endogenous. We have identified conditions under which firms' owners delegate both long-run decisions (such as cost reducing R&D expenditures) and short-run decisions (such as output or prices) to their managers, as well as those conditions under which they delegate only short-run decisions. We have, thus, obtained the equilibrium organizational structure configurations that arise in the market under various circumstances. In our analysis, we have focussed on firms' owners delegation strategies that are time consistent, i.e., those strategies that owners have no incentive to revise when firms' R&D expenditures have been decided upon.

We have shown that overall industry R&D expenditures are the highest when firms' owners select different organizational structures in a Cournot homogenous good market. That is, when one firm's owners choose to delegate both R&D and output decisions to their manager, while the rival's owners delegate only the output decision to their managers. This Asymmetric Delegation configuration arises in equilibrium whenever the firms' initial production technology is rather efficient (initial marginal cost is low enough). In this case, ex-ante identical firms end up being ex-post asymmetric in terms of their R&D effort, output and profits. This is in line with the empirical evidence (Colombo and Delmastro, 2004).

Further, we have identified conditions under which symmetric delegation configurations emerge in equilibrium. In particular, Universal FD arises in equilibrium when goods are close substitutes and firms compete in quantities. While Universal PD arises in equilibrium under Bertrand competition and when goods are poor substitutes under Cournot competition.

Finally, we have shown that market and societal incentives are not always aligned. For instance, while welfare is higher under an Asymmetric Delegation configuration in the Cournot homogenous goods case, the equilibrium configuration is Universal FD as long as the initial production technologies are not too efficient.

Our findings provide some guidelines for future empirical research on the effects of firms' owners managerial incentives on oligopolistic firms' innovation investments and market performance, which is so far scant and inconclusive. Empirical analyses should start with a detailed study e.g. in high technology industries, regarding the effects of the use of managerial contracts as an incentive mechanism to increase R&D investments. A number of testable hypotheses emerges from our analysis. For instance, R&D investments and profitability are expected to be higher in firms that strategically delegate innovation decisions to their managers, offering them incentives to deviate from strict profit maximization. Another testable hypothesis could be that the probability of a firm delegating R&D investments to non profit maximizing managers is lower when the firms are initially endowed with efficient production technologies.

Our analysis was carried out in a duopolistic market structure with specific functional forms - linear demand functions, constant marginal costs and quadratic cost reducing R&D costs. Our conjecture is that in this simple setting, all the important insights regarding firms' owners incentives to delegate short- and long-run decisions to their managers and the resulting organizational structures are obtained. Of course, it remains for future research to be checked to which extent our main results are valid in oligopolistic markets under more general demand and cost functions.

Appendix

Appendix A1: Proof of Proposition 1

By comparing the equilibrium managerial incentive parameters under the Universal FD and PD configurations, given by (9) and (15), it can be checked that $a^{FD} > a^{PD}$ always. Further, by comparing the respective equilibrium R&D investments, given by (10) and (14), it can be checked that $x^{FD} > x^{PD}$ always. Turning to the equilibrium outputs under Universal FD and PD,given by (10) and (15), it can be checked that $q^{FD} > q^{PD}$ if and only if $c < \widehat{c}_q(r)$. Finally, by comparing the respective equilibrium profits, given by (10) and (15), it can be checked that $\Pi^{FD} > \Pi^{PD}$ if and only if $c < \widehat{c}_\Pi(r)$.

Appendix A2: Proof of Proposition 2

By comparing equilibrium managerial incentive parameters in the Asymmetric Delegation configuration, given by (20) and (21), with those under Universal FD and PD, it can be checked that $a_1^A < a^{PD} < a^{FD} < a_2^A$ always. Further, by comparing the respective equilibrium R&D investments (see (22)), it can be checked that $x_1^A > x^{FD} > x^{PD} > x_2^A$ always. Turning to equilibrium outputs and profits (see (22) and (23)), it can be verified that $q_1^A > \max[q^{FD}, q^{PD}] > q_2^A$ and $\Pi_1^A > \max[\Pi^{FD}, \Pi^{PD}] > \Pi_2^A$ under all parameter values. Finally, by comparing industry output and profits in the Asymmetric Delegation configuration with the respective ones under Universal FD and PD, it can be checked that $Q^A = q_1^A + q_2^A > \max[Q^{FD}, Q^{PD}]$ and $T\Pi^A = \Pi_1^A + \Pi_2^A < \min[T\Pi^{FD}, T\Pi^{PD}]$ under all parameter values.

Appendix B: Proof of Proposition 5

Total welfare under Universal Full Delegation, Universal Partial Delegation, Asymmetric Delegation configuration and Non-Delegation are given by the following expressions, respectively:

$$TW^{FD}(c,r) = \frac{rx_n^{FD}}{8}[12(1-c) - (9r-4)x_n^{FD}]A^2 > 0$$

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

$$TW^{A}(c,r) = \frac{2r(1-c)^2\{756r - 84 + r^2[2370r - 2113 + r^2(140r - 999)]\}A^2}{(3r-2)^2[6 + r(8r-25)]^2} > 0$$

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

Taking the differences it can be checked that $TW^N < TW^{FD} < TW^{PD} < TW^A$ for all permissible parameters values.

Notes

[1]In contrast, their capital spending in the same period increased by only 2 percent. See for instance, Leary, 2002 and Mandel et al., 2006.

[2]Del Monte and Pagani (2003) offer a comprehensive literature review on the subject.

[3]The term "strategic delegation" was introduced by the seminal contribution of Schelling (1960). The use of strategic delegation modeling can be justified on the grounds of Fershtman and Judd (1990), who support that the basic results derived in a strategic delegation context are robust when asymmetries of information exist.

[4]See Jansen et al., 2009; Manasakis et al., 2010 and Wang and Wang, 2010, for alternative delegation schemes in different industries.

[5]It is straightforward from the VFJS model that, for given technologies, delegation of decisions from owners to managers is always a dominant strategy. Henceforth, cases in which an owner delegates no decisions to his manager and sticks to pure profit maximization are not considered here. The (Non-Delegation, Non-Delegation) configuration is analyzed only as a benchmark case in Section 3.

[6]Zhang and Zhang (1997) firstly introduced strategic delegation of both output and R&D investments. Kopel and Riegler (2006) amend the Zhang and Zhang solution, indicating that, due to computational mistakes, their propositions do not hold.

[7]Gürtler (2008), in a principal agent model, describes the case in which the owner (principal) endogenously selects between delegating only one of the two available decisions (Partial delegation) and delegating all available decisions to the agent (Complete delegation). However, he does not assume any classification of these decisions. We assume that, in a strategic delegation model, the owner has to choose between delegate only short run decisions (Partial delegation) or both short run and long run decisions (Full delegation).

[8]Based on the findings of Kopel and Riegler (2005), in our paper, we assume away R&D spillovers. This allows us to focus our analysis on alternative factors that may affect owners' choice of the type of decisions delegated, such as their ability to commit to specific delegation strategies, product substitability, and mode of competition.

[9]i.e., that (i) the second order conditions and stability conditions are satisfied and (ii) that equilibrium

marginal cost, output, R&D expenditures and profits are always positive.

[10]One can reasonably argue that moral hazard issues may arise in a strategic delegation context. Nevertheless, these issues are often ignored by the strategic delegation literature. This literature rather focusses on the use of delegation of authority from owners to managers in order to render credible non-strictly profit maximizing strategies which managers can employ, and which the owners themselves are unable to follow. See Vickers (1985), Fershtman and Judd (1987), Sklivas (1987), Miller and Pazgal (2001; 2002; 2005), Jansen et al. (2007; 2009) and Ritz (2008).

[11]A standard assumption in the strategic delegation literature is that firms' owners have all the bargaining power during negotiations with their managers and they thus offer "take-it-or-leave-it" incentive contracts to their managers that leave them with their reservation value.

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

[13]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.

[14]The timing of the game reflects common real business practices where firms first decide over their long-run plans (such as R&D expenditures) and, according to them, decide simultaneously about their short-run variables (such as quantities or prices). See, among others, Zhang and Zhang (1997) and Barcena-Ruiz and Casado-Izaga (2005).

[15]It is well-known in the literature that the Non-Delegation strategy N is strictly dominated by both PD and FD strategies. Thus, w.l.o.g. we can ignore the N strategy in our analysis.

[16]It can be easily checked that the second order and the stability conditions are satisfied as long as $a_i > 0$.

[17] $\frac{\partial x_i^{FD}}{\partial a_i} = -\frac{8(3r-2a_j)(3r-4a_j)(9cr-4)A}{[27r^2+16a_i a_j-24r(a_i+a_j)]^2} < 0$ and $\frac{\partial x_i^{FD}}{\partial a_j} = \frac{12r(3r-4a_i)(9cr-4)A}{[27r^2+16a_i a_j-24r(a_i+a_j)]^2} > 0$

[18]Moreover, it can be checked that the second order and stability conditions are satisfied at (a^{FD}, a^{FD}).

[19]It can be easily checked that the second order conditions are satisfied. The stability conditions are also satisfied when $x_i = x_j$.

[20]It can be checked that second order and stability conditions are satisfied.

[21]In fact, $\widehat{c}_{\Pi}(r)$ varies between 0.444637 and 0.45 and is not monotonic in r.

[22]More specifically, $x^{PD} > x^N > x_2^A$, and $q_2^A < q^N < \min[q^{FD}, q^{PD}]$, i.e., only the follower in incentives firm

2 invests less and produces less than any firm under no delegation.

[23]This expression is too long to be included in the text. However, it is available from the authors upon request.

[24]For each extension discussed below, the detailed analysis is available from the authors upon request.

[25]To avoid corner solutions we assume that $\gamma < 0.85$, i.e., that the two goods are not too close substitutes. As above, we also assume that $r = 5$.

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Figure 1: The timing of the game.

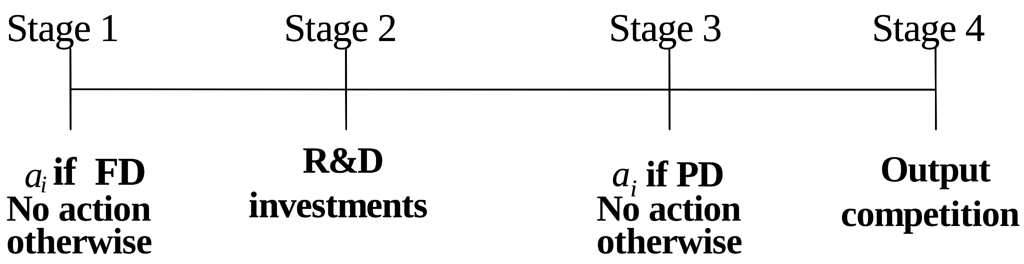

Figure 2:

Table 1: Owners' profits in the ensuing 2×2 matrix game.

	FD	PD
FD	Π^{FD}, Π^{FD}	Π_1^A, Π_2^A
PD	Π_2^A, Π_1^A	Π^{PD}, Π^{PD}

Figure 3: Emerging equilibria under no commitment.

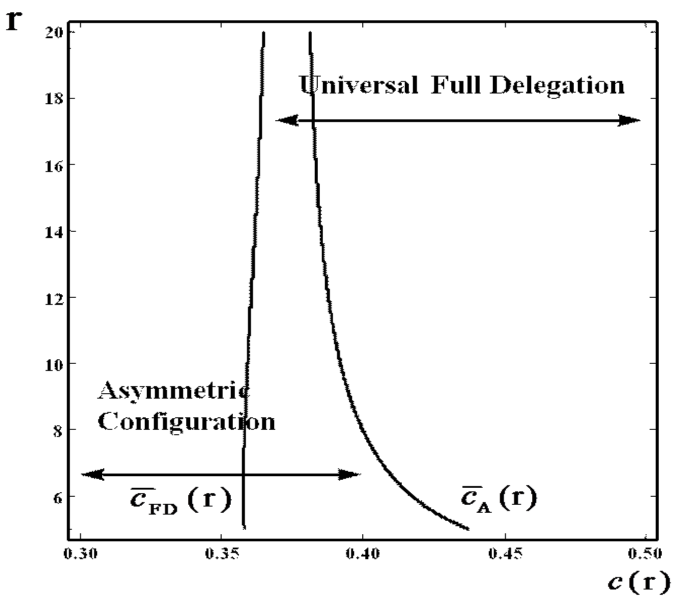

Figure 4: