Organizational structure, strategic delegation and innovation in oligopolistic industries

Evangelos Mitrokostas[*] Emmanuel Petrakis[†]

University of Portsmouth University of Crete

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Abstract

We endogenize firms' organizational structures in a homogenous goods duopoly where firms invest in cost reducing R&D and compete in quantities, and examine their impact on R&D efforts and market performance. Each firm's owner can either delegate to a manager both market competition and R&D investment decisions (Full Delegation strategy) or delegate the market competition decision alone (Partial Delegation strategy). We show that when the initial marginal cost is relatively high, Universal Full Delegation emerges in equilibrium. Otherwise, an asymmetric equilibrium with one owner choosing a Full Delegation strategy and the other a Partial Delegation strategy arises. Finally, Universal Partial Delegation can arise in equilibrium only if competition is in prices.

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[*]Corresponding author: Economics and Finance Subject Group, Portsmouth Business School, University of Portsmouth, Richmond Building, Portland Street, Portsmouth, Hampshire, PO1 3DE, United Kingdom. Tel: +44 (0) 2392844133. Email: evangelos.mitrokostas@port.ac.uk

[†]Email: petrakis@econ.soc.uoc.gr.

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 (e.g., Fama and Jensen 1983, Jensen and Meckling, 1976). A large body of the theoretical literature on delegation analyzes the incentives of owners to strategically delegate decisions to their managers that lead away from profit maximization. A leading model within this literature is the VFJS model [3] which assumes that owners offer a sales bonus to their managers in order to influence the behavior of rival firms in their favor. Recently, researchers have focussed their attention on the investigation of the proper incentives for managers that foster firms' R&D investments.[4]

This paper aims to investigate the relation between strategic managerial contracts, innovation and firm performance in a market in which owners choose their firms' organizational structure. In particular, 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 him (Partial Delegation strategy). More specifically, we 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? What are the welfare effects of each configuration of organizational structures? Are the market and societal incentives aligned?

To do so, we consider a homogenous Cournot duopoly. We follow the VFJS model, with 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 basic 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 makes a "take-it-or-leave-it" offer to his manager specifying the incentive parameter for both the R&D and output decisions. Otherwise, he takes no action. In the second stage, R&D investments are chosen 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 makes a "take-it-or-leave-it" offer to his manager specifying the incentive parameter for the output decision alone. In the last stage, managers compete in quantities. We also consider a pre-play game in which in stage 0, firms' owners announce (and precommit) to the delegation strategies that they will follow in the future.

In this context, the firms' organizational structures arise 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 choose the FD strategy; Universal Partial Delegation, (PD, PD), in which both firms' owners choose 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]

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 any firm in the Universal FD and PD configurations and also than its rival firm that chooses the PD strategy. Moreover, the firms' profits are higher under the Universal

FD than under the Universal PD configuration as long as firms endowed initially with an efficient technology. There is scant empirical evidence on the relation between R&D efforts and delegation schemes which is mixed. Our results are partially in line with a 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). [6]

Regarding the equilibrium configuration of organizational structures, we find that the Universal PD is never an equilibrium configuration. In the basic game, the Universal FD configuration arises in equilibrium, but only if the initial marginal cost is high enough. Otherwise, the asymmetric delegation is an equilibrium configuration. 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), examining delegation decisions in a sample of 438 Italian manufacturing firms, report that in some cases firms' owners delegate only short-run decisions, such as output, to their managers, while in others they delegate long-run decisions, such as R&D investments, as well.

We further show that in the pre-play game, the Universal FD is the unique equilibrium configuration. Hence, we point out that the assumption used in the literature about the existence of a pre-play game stage in which firms' owners announce and precommit to the delegation strategies that they will follow in the future is not innocuous.

Regarding welfare, we show that all organizational structure configurations lead to higher welfare than under no delegation. Moreover, that the Asymmetric configuration leads to the highest welfare, while the Universal FD configuration leads to the lowest welfare. As a consequence, market and societal incentives are not always aligned.

Finally, we investigate the impact of R&D spillovers, as well as of price competition, on the equilibrium market outcomes. As expected, the existence of low R&D spillovers does not alter our main findings. However, high spillovers may lead to reversals in the equilibrium output rankings and, more importantly, to Universal FD being the unique equilibrium configuration. Moreover, in contrast to quantity competition, under price competition, Universal PD arises in equilibrium for all degrees of product substitutability. 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.

The contribution of our paper is two-fold. First, we contribute to the broad literature that examines the effects of alternative firms' organizational structures on the firms' R&D investments, market outcomes and welfare, as well the endogenous emergence of these alternative organizational structures in the market. The bulk of this literature focuses on agency theory issues that neglect strategic interactions arising among oligopolistic firms.[7] Our paper belongs to a recent branch of the literature that studies how strategic delegation of decisions from owners to managers affects firm's R&D investments and production decisions. Zhang and Zhang (1997) were the first to study how the separation of ownership and management affects firm's R&D investment and output decisions. They consider a Cournot duopoly in which both firms choose simultaneously either the Full Delegation or the No Delegation strategy. They find that, under the Full Delegation strategy, if R&D spillovers are low enough, 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.[8] In a similar vein, Kopel and Riegler (2006, 2008) endogenize the selection between Non-Delegation and Full Delegation, by assuming a pre-play game in which rival owners announce and precommit to their future delegation strategies. In this setup, Kopel and Riegler (2008) show that R&D spillovers do not affect firms' owners choice of organizational structure, 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' choice of organizational structure. Second, besides the pre-play game scenario considered in the literature so far, we also examine the time consistent scenario in which firms' owners are unable to announce and precommit to the delegation strategies that they will follow in the future. 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.[9] In contrast to the received literature, we show that Full Delegation may not be a firm's owners' choice of organizational structure if owners can optimally adjust their delegation strategies over time. This highlights that owners precommiting to future delegation strategies is not an innocuous assumption and has profound effects for market and societal outcomes.

Second, our paper contributes to the literature that investigates the endogenous emergence of asymmetric performance among ex-ante symmetric firms operating in the same industry.[10] In particular, 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). Yet, these papers ignore the role of innovation as a source of asymmetric performance. When firms can spend on cost-reducing R&D before deciding their outputs, we show that ex ante symmetric firms in an industry may end up being ex post asymmetric in their performance, whenever firms' organizational structures result from their owners' strategic selection of managerial incentives schemes. 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. This finding is in sharp contrast to the received literature on the strategic use of managerial incentive contracts (VFJS model; Miller and Pazgal 2001, 2002, 2005; Jansen et al. 2007, 2009). In the absence of R&D investments, their main finding is that ex ante symmetric firms perform equally in equilibrium, because firms' owners choose the same incentive contract to induce a more aggressive behavior of their managers in the market. Instead, by including R&D investments and Partial Delegation in the firm's spectrum of decisions, we show that asymmetric equilibria could arise in which some firms choose not to delegate all decisions to their managers.

The rest of the paper is organized as follows. Section 2 presents the basic model. In Section 3, the alternative organizational structure configurations are analyzed and compared among them. Section 4 investigates the conditions under which alternative organizational structure configurations arise in equilibrium. Section 5 conducts a welfare analysis. Section 6 discusses price competition, while Section 7 examines the robustness of our main results in the presence of R&D spillovers. Finally, Section 8 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 $P(Q) = 1 - Q$, 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, with $c < 1$. 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), with the parameter r measuring the effectiveness of the R&D technology. 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. Firm i's total cost is: $C_i(.) = (c - x_i)q_i + \frac{r}{2}x_i^2$.[11] To guarantee well-behaved interior solutions under all parameter values[12] we make the following assumption:

Assumption 1: $.3 \leq c < 1$ and $r \geq 5$.

Assumption 1 requires that both the initial marginal cost and the effectiveness of the R&D technology are not too low.

Firm i's profits are:

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

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 firm's profits, while "manager" is an agent hired by the owner to make decisions on a spectrum of tasks.[13] Each firm's owner can compensate his manager by offering a "take-it-or-leave-it" incentive contract to him.[14] The incentive contract 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.[15] 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,[16] and a_i, $a_i \leq 1$, is the *managerial incentive parameter.* 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 himself.[17,18] In order to investigate the delegation strategies that firms' owners are expected to follow in equilibrium, as well as the effects of such strategies on market outcomes, we consider a basic game and a pre-play game.

The basic game is a four-stage game with *observable actions.* The sequence of moves unravels as follows:

Stage 1: Each firm i's owner can make an offer of a "take-it-or-leave-it" contract to his manager specifying the incentive parameter for both the R&D and output decisions, a_i^{FD}, in which case we say that owner i follows an FD strategy. The manager then accepts or rejects the offer. If, instead, a firm's owner prefers to keep the R&D decision for himself (i.e., if he opts for a PD strategy), he takes *no action* at this stage.

Stage 2: Each firm i's decision maker (its manager in case of FD strategy or its owner in case of PD strategy) chooses the firm's R&D investment level in order to maximize its objective function.

Stage 3: If a firm's owner has opted for the PD strategy in Stage 1, he makes an offer of a "take-it-or-leave-it" contract to his manager specifying the incentive parameter for the output decision, a_i^{PD}. The manager then accepts or rejects the offer. Otherwise, the owner takes no action.

Stage 4: Each firm i's manager chooses its firm's output.[19]

The above timing of the game guarantees that all decisions are *time consistent*. In particular, a firm i's owner choice of an incentive parameter a_i^{PD} in Stage 1 cannot be credible, because it is common knowledge that he will have incentives to revise this parameter choice at Stage 3, once firms' R&D decisions have been taken in Stage 2. In the same vein, firms' R&D decisions are expected to be taken strategically in Stage 2 in order to influence the choice of the incentive parameters in Stage 3 of those owners who have opted for a PD strategy.

We also consider a pre-play game with observable actions. In the latter game, we add a Stage 0 to the basic game.

Stage 0: Each firm i's owner announces (and precommits to) the delegation strategy that will follow in the continuation of the game. More specifically, announcing an FD strategy implies that the firm i's owner plans to choose the incentive parameter for his manager a_i^{FD} in Stage 1, while announcing a PD strategy implies that he will select the incentive parameter a_i^{PD} in Stage 3.

Both games are solved by employing the Subgame Perfect Nash Equilibrium (SPNE) solution concept.

3 Delegation Strategy Configurations

In this section we analyze the alternative delegation strategy configurations that may arise in equilibrium. Due to symmetry, these configurations reduce to the following three: *Universal Full Delegation* (FD, FD), *Universal Partial Delegation* (PD, PD), and *Asymmetric Delegation* (FD, PD).

It should be noted that the "Non-Delegation" configuration, (N, N), (i.e., when R&D and output decisions are taken by firms' owners), corresponds to the special case in which $a_i^{FD} = a_i^{PD} = 1$. We briefly discuss this as a benchmark case.[20] 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, $q_i = R_q^N(q_j) = \frac{1-q_j-(c-x_i)}{2}$. The respective one in the R&D investments stage is, $x_i = R_x^N(x_j) = \frac{4(1-c-x_j)}{9r-8}$. Observe that both firms' outputs and R&D investments are strategic substitutes. Equilibrium output, R&D investments, and profits are, respectively:

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

Turning to our main analysis, the last stage of the game is common across all three delegation strategy configurations. Each firm i's manager sets output to maximize (2). From the first order condition, the reaction function of manager i is:

$$q_i = R_q(q_j) = \frac{1-q_j-a_i(c-x_i)}{2} \tag{4}$$

Manager i thus perceives $a_i(c-x_i)$ as its firm's marginal production cost, which is lower than the true marginal cost for all $a_i < 1$. The lower the incentive parameter that owner i sets, the lower is the marginal cost that manager i perceives and thus, the more aggressive he becomes in the output setting game. Solving the system of first order conditions, firm i's output is:

$$q_i(x_i, x_j, a_i, a_j) = \frac{1-2a_i(c-x_i)+a_j(c-x_j)}{3} \tag{5}$$

The following observations are in order. First, $\frac{\partial q_i}{\partial a_i} < 0$, i.e., the lower the incentive parameter that owner i sets, the higher is the aggressiveness of his manager and thus the higher is firm i' s output. In contrast, $\frac{\partial q_i}{\partial a_j} > 0$, that is, a lower managerial incentive set by the rival owner leads firm i' s manager to decrease output. Second, $\frac{\partial q_i}{\partial x_i} > 0$ and $\frac{\partial q_i}{\partial x_j} < 0$. Clearly, as firm i's R&D increases, the firm's perceived (and true) marginal cost decreases, leading his manager to set a higher output. The opposite holds when the rival firm increases its R&D investments and becomes relatively more efficient in the market.

3.1 Universal Full Delegation (FD, FD)

Consider first the Universal FD configuration.[21] In the third stage there is no action. 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: $M_i(x_i, x_j, a_i, a_j) = [q_i(\cdot)]^2 - a_i \frac{r}{2} x_i^2$. The latter 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 this case, not only the marginal production cost, but also the R&D costs of the firm are "discounted" by a factor equal to the incentive parameter set 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,[22] the reaction function of manager i is:

$$x_i = R_x^{FD}(x_j) = \frac{4[1 - 2a_i c + a_j(c - x_j)]}{9r - 8a_i} \tag{6}$$

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 is the rival firm's R&D investment level, the lower is 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:

$$x_i^{FD}(a_i, a_j) = \frac{12r(1 - 2a_i c + a_j c) - 16a_j(1 - a_i c)}{27r^2 - 24r(a_i + a_j) + 16a_i a_j} \tag{7}$$

It can be checked that under Assumption 1, $\frac{\partial x_i^{FD}}{\partial a_i} < 0$ and $\frac{\partial x_i^{FD}}{\partial a_j} > 0$. 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 observations reveal that owners may strategically choose the incentive parameters for their managers in the first stage in order each to influence his rival manager's 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 makes an offer of a "take-it-or-leave-it" contract to his manager specifying the incentive parameter a_i, so as to maximize profits $\Pi_i^{FD}(a_i, a_j)$. The latter can be obtained by substituting (7) into (5) and (1). Each manager then accepts the offer, as it satisfies his participation constraint. From the first order condition, the reaction function of owner i is:

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

It can be checked that under Assumption 1, $\frac{\partial R_a^{FD}}{\partial a_j} < 0$,[23] 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:

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

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:

$$x^{FD} = \frac{16(9r-2) - 3cr(45r-4) + \Psi}{24r(9r-2)}; \quad q^{FD} = \frac{3r}{4}x^{FD}; \quad \Pi^{FD} = \frac{rx^{FD}}{8}[6(1-c) - (9r-2)x^{FD}] \tag{10}$$

3.2 Universal Partial Delegation (PD, PD)

We next consider the Universal Partial Delegation configuration. In the third stage, each owner i makes an offer of a "take-it-or-leave-it" contract to his manager specifying the incentive parameter a_i, so as to maximize profits. The latter from (7), and after some manipulations, can be written as: $\Pi_i(a_i, a_j, x_i, x_j) = [q_i(\cdot)]^2 - (1-a_i)(c-x_i)q_i(\cdot) - \frac{r}{2}x_i^2$. Each manager then accepts the offer, as it satisfies his participation constraint. From the first order condition,[24] the reaction function of owner i is:

$$a_i = R_a^{PD}(a_j) = \frac{6c - 1 - 6x_i - a_j(c - x_j)}{4(c - x_i)} \tag{11}$$

Note that $\frac{\partial R_a^{PD}}{\partial a_j} < 0$. As above, managerial incentives are strategic substitutes. 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.

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

$$a_i^{PD}(x_i, x_j) = \frac{6c - 1 - 8x_i + 2x_j}{5(c - x_i)} \tag{12}$$

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 investment increases, 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 relatively 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 invest on R&D strategically in stage two in order to influence the incentive parameters choices in stage three. Indeed, owner i may invest relatively more on R&D in order to prevent his rival owner from making his manager too aggressive.

In the third stage there is no action. 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 $q_i^{PD}(x_i, x_j) = \frac{2}{5}(1 - c + 3x_i - 2x_j)$.

From the first order condition,[25] the reaction function of owner i is:

$$x_i = R_x^{PD}(x_j) = \frac{12(1 - c - 2x_j)}{25r - 36} \tag{13}$$

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:

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

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

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

It can be checked that $0 \leq a^{PD} \leq 1$. 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.

3.3 Asymmetric Delegation Configuration (FD, PD)

We finally turn to the Asymmetric Delegation configuration case. Without loss of generality, assume that owner 1 follows the FD strategy and owner 2 the PD one. In the third stage, owner 2 makes an offer of a "take-it-or-leave-it" contract to his manager specifying the incentive parameter a_2, so as to maximize profits that, as above, are given by $\Pi_2(x_1, x_2, a_1, a_2) = [q_2(\cdot)]^2 - (1-a_2)(c-x_2)q_2(\cdot) - \frac{r}{2}x_2^2$. Manager 2 then accepts the offer, as it satisfies his participation constraint. From the first order condition, the incentive parameter of owner 2 is:

$$a_2^A(x_1, x_2, a_1) = \frac{6c - 1 - 6x_2 - a_1(c - x_1)}{4(c - x_2)} \tag{16}$$

Observe that owner 2, who is follower in setting the managerial incentive, 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:

$$x_1 = R_x^A(x_2) = \frac{3[1 + (2 - 3a_1)c - 2x_2]}{8r - 9a_1}; \quad x_2 = R_x^A(x_1) = \frac{1 - 2c + a_1(c - x_1)}{2(r - 1)} \tag{17}$$

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 (a lower $a_1$set by his owner in the first stage) 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:

$$x_1^A(a_1) = \frac{3(r-2)+6cr-3a_1c(3r-2)}{8r(r-1)-3a_1(3r-2)}, \; x_2^A(a_1) = \frac{4r-8cr+a_1[-6+c(6+4r)]}{8r(r-1)-3a_1(3r-2)} \tag{18}$$

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 makes an offer of a "take-it-or-leave-it" contract to his manager specifying the incentive parameter a_1, so as to maximize his profits which can be written as: $\Pi_2 = \frac{1}{2}[q_2^A(x_1^A(\cdot), x_2^A(\cdot), a_1, a_2^A(\cdot))]^2 - \frac{r}{2}[x_2^A(\cdot)]^2$. Manager 1 then accepts the offer, as it satisfies his participation constraint. From the first order condition, we obtain the equilibrium incentive parameter for manager 1:

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

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

$$a_2^A = \frac{(r+2)[6+r(4r-17)]-4cr[r(7r-25)+10]}{2[6+r(4r-17)]-cr[(24r-83)r+34]} \tag{20}$$

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 does. 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:

$$x_1^A = \frac{6(r-2)(1-c)}{r(8r-25)+6};\ x_2^A = \frac{2(1-c)(4r^2-17r+6)}{(3r-2)[r(8r-25)+6)};\ q_1^A = \frac{2r}{3}x_1^A;\ q_2^A = rx_2^A \tag{21}$$

$$\Pi_1^A = \frac{2r(r-2)^2(1-c)^2}{(3r-2)[r(8r-25)+6]};\ \Pi_2^A = \frac{2r(r-1)(1-c)^2[r(4r-17)+6]^2}{(3r-2)^2[r(8r-25)+6]^2} \tag{22}$$

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 across the three alternative delegation configurations, the following Proposition results.

Proposition 1 *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* $q_2^A < \min[q^{FD}, q^{PD}]$. *Moreover,* $q^{FD} < q^{PD}$ *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) $\Pi_1^A > \max[\Pi^{FD}, \Pi^{PD}]$ *and* $\Pi_2^A < \min[\Pi^{FD}, \Pi^{PD}]$. *Moreover,* $\Pi^{FD} > \Pi^{PD}$ *if and only if* $c < \widehat{c}_\Pi(r)$ *where* $\widehat{c}_\Pi(r) \approx 0.45$.[26]

(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* $T\Pi^k = 2\Pi^k$, $k = FD, PD$

We first discuss the comparison between the two symmetric delegation configurations and then turn to the comparison of the latter with the asymmetric one. Regarding the symmetric delegation configurations, 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 incentive parameter, while only output costs are discounted under Universal PD. Thus, in principle, the FD configuration may turn out to be costlier for the owners 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 rationale behind Proposition 1(ii) is straightforward. 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 than under Universal PD.

As regards 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 than under Universal PD (Proposition 1(ii)), and this tends to lead to higher output in the former than in the latter case. Second, under Universal FD owners set a lower level of aggressiveness for their managers, leading thus to lower output than under Universal PD (Proposition 1(i)). If $c > \widehat{c}_q(r)$, the first positive effect dominates the second negative effect and thus 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 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 (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 than Universal FD.

Turning to the comparison of the asymmetric delegation configuration with the symmetric ones, the intuition behind Proposition 1(i-iv) goes as follows. Now 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, in turn, 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 (Proposition 1(v-vii)).

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.[27] 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 precommit 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 assumption that owners announce and precommit to specific delegation contracts 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 The Pre-play Game

Following the bulk of the literature, in this subsection we investigate the equilibrium delegation configurations under the assumption that firms' owners announce (and precommit to) their delegation strategies. This is reflected in the pre-play game in which, in Stage 0, firms' owners choose between the FD and PD strategy (before they set their respective incentive parameters in Stage 1 and Stage 3, respectively). Table 1 provides the owners' profits in the ensuing in Stage 0 2×2 matrix game.

<<PUT TABLE 1 HERE>>

An immediate consequence of Proposition 1(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 lower profits ($\Pi_2^A < \Pi^{FD}$). Therefore, the unique equilibrium of the pre-play game is (FD, FD). The following Proposition summarizes:

Proposition 2 *If firms' owners are able to announce (and precommit) to the delegation strategies that will follow in the sequel, 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 The Basic Game

In this subsection we relax the assumption that there is a Stage 0 in which owners announce (and precommit to) their future delegation strategies. We thus turn to the equilibrium analysis of the basic game. As is standard in this type of games, we first propose a candidate equilibrium delegation configuration, and then check whether it survives all possible deviations.[28]

The three delegation configurations analyzed in Section 3 are *candidate equilibria* that should be tested against all possible deviations. In particular, regarding the Universal FD delegation configuration, there is (due to symmetry) only one possible deviation. Given owner i's FD strategy with incentive parameter a^{FD}, does owner j has incentives to deviate by taking no action in Stage 1, thus switching to a PD strategy whose incentive parameter will be chosen later on in Stage 3? As regards the Universal PD delegation configuration, there is again one possible deviation. If owner j expects that his rival will follow a PD strategy and will set the respective incentive parameter in Stage 3, does he have incentives to switch to an FD strategy, i.e., to offer a contract to his manager in Stage 1? Finally, regarding the asymmetric delegation configuration, there are two possible deviations. First, given owner 1's FD strategy with incentive parameter a_1^{FD}, does owner 2 has incentives to switch to an FD strategy and set its (best-response) incentive parameter in Stage 1 too? And second, if owner 1 expects that his rival will follow a PD strategy and will set the incentive parameter in Stage 3, does he have incentives to switch to a PD strategy as well? The formal analysis is relegated to the Appendix, with the following Proposition summarizing our findings:

Proposition 3 *(i) If $c \geq \bar{c}_{FD}(r)$, then the Universal Full Delegation is an equilibrium config-*

uration.

(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.

Figure 2 illustrates our results. Universal Full Delegation is an equilibrium configuration in the region to the right of the $\overline{c}_{FD}(r)$ curve, while Asymmetric delegation configuration is an equilibrium in the region to the left of $\overline{c}_A(r)$ curve. 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.

<<PUT FIGURE 2 HERE>>

It is worth stressing that Proposition 3 is in line with the empirical evidence provided by Colombo and Delmastro (2004) that shows that the two delegation strategies often coexist in equilibrium.

The intuition behind Proposition 3(i) 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 as a follower in setting managerial incentives owner will typically direct his manager to a relatively less aggressive behavior. 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.

As regards Proposition 3(ii), the intuition goes as follows. We have seen that in the Asymmetric Delegation configuration, 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 resulting Universal Full Delegation deviation 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 a PD to an 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.

Finally, regarding Proposition 3(iii), the reasoning is along the lines of that offered when comparing the asymmetric and symmetric delegation configurations (see Section 3). There are strong incentives to become a leader in setting managerial incentives and thus, (PD, PD) can never arise as an equilibrium configuration.

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:

$$TW^m = CS^m + T\Pi^m, \text{ with } m = PD, FD, A, N \tag{23}$$

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 the Appendix. Our results from the total welfare comparison are included in the following Proposition:

Proposition 4 *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 4 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 under Non-Delegation.

Moreover, Proposition 4 informs us that the Asymmetric Delegation configuration leads to the highest welfare. This is an immediate consequence of Proposition 1. As we saw, industry output is higher under Asymmetric Delegation than under any of the two symmetric delegation configurations (Proposition 1(vi)). 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 1(vii), is always lower under the Asymmetric than under any symmetric delegation configuration.

Further, according to Proposition 4, 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 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 4 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 Price competition

In this section we consider how our main results may change if alternatively we assume that firms compete in prices, instead of quantities. We built upon the framework of Section 2 with one important departure, we assume that firms produce differentiated products. In particular, we assume that each firm faces the following (inverse) demand function: $p_i = 1 - q_i - \gamma q_j$, $i, j = 1, 2$; $i \neq j$, 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 $r = 5$. Thus we assume that each firm produces one brand of a differentiated good and faces the following demand function: $q_i = \frac{(1-\gamma)-p_i+\gamma p_j}{1-\gamma^2}$ $i, j = 1, 2$; $i \neq j$.[29]

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.[30]

7 R&D Spillovers

Throughout the paper we have assumed that there are no R&D spillovers. Let us now examine how our main results may change in the presence of R&D spillovers. Following Zhang and

Zhang (1997) and Kopel and Riegler (2006, 2008), the firm i's cost and profit functions now become, $C_i(.) = (c - x_i - \theta x_j)q_i + \frac{r}{2}x_i^2$ and $\Pi_i = (1 - q_i - q_j)q_i - (c - x_i - \theta x_j)q_i - \frac{r}{2}x_i^2$, respectively, where $\theta \in [0, 1]$ measures the size of the spillover effect. The rest of the specifications are as in the basic model. Following Kopel and Riegler (2006), here too closed form solutions cannot be obtained, and thus we have to resort to numerical simulations. Assuming that $r = 10$, and keeping c as a parameter, we consider a fine grid of values of the spillover parameter θ, ranging from .05 to .95. Table 2 reports a sample of our simulations for $c = .5$ and $\theta = .05, .5,$ and .95, i.e., for the cases of low, intermediate and high spillovers, respectively.[31]

Our simulations indicate that, for relatively low spillovers, most of our main results are qualitatively similar to those under no spillovers. In particular, Propositions 1 and 2 hold intact (see Table 2 for $\theta = .05$). Regarding Proposition 3, we still have two equilibrium delegation configurations, the Asymmetric and the Universal FD ones. Interestingly, the Asymmetric configuration is an equilibrium configuration for a wider range of c values, while for the Universal FD configuration the opposite holds. For instance, $\bar{c}_{FD}(\theta = .05) = .485 > .36 = \bar{c}_{FD}(\theta = 0)$ and $\bar{c}_A(\theta = .05) = .47 > .39 = \bar{c}_A(\theta = 0)$. Moreover, there is a range of intermediate c values for which there is no equilibrium in pure strategies. This is in contrast to the case of no spillovers where multiple equilibria arise under some values of c (see Figure 1).

On the other hand, for intermediate levels of spillovers there are a few ranking reversals regarding Proposition 1. For instance, managers invest more in R&D under the Universal FD configuration comparing to all other configurations, leading to lower output and higher profits than under the Universal PD configuration (see Table 2 for $\theta = .5$). Yet, in the pre-play game, Universal FD is the unique equilibrium configuration, i.e., Proposition 2 holds for intermediate θ. Considering Proposition 3, in contrast to the low spillovers case, Universal FD delegation configuration arises for low values of c, while the opposite is true for the Asymmetric configuration delegation. Non-existence of equilibrium in pure strategies is observed for intermediate values of c.

Finally, for relatively high spillovers, managers still are overinvesting in R&D under the Universal FD configuration comparing to all other configurations, however owners under the

Universal PD configuration increase their R&D investments as well. This leads to higher output and lower profits under the Universal FD than under the Universal PD configuration (see Table 2 for $\theta = .95$). Proposition 2 holds also for high θ. Interestingly, regarding Proposition 3, in this case there is a unique equilibrium, the Universal FD configuration equilibrium.

<<PUT TABLE 2 HERE>>

8 Conclusions

We have investigated the relation between strategic managerial incentives, innovation and firm performance 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.

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 efficient (initial marginal cost is low). In this case, ex-ante identical firms end up being ex-post asymmetric in terms of their R&D effort, output and profits. Further, we have identified conditions under which symmetric delegation configurations emerge in equilibrium. In particular Universal PD arises in equilibrium under Bertrand competition.

We have also demonstrated that market and societal incentives are not always aligned. 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 relatively inefficient. Finally, our main results remain robust under the existence of R&D spillovers, provided that these spillovers are relatively low. Otherwise, in the existence of high level of R&D spillovers Universal FD may be the only equilibrium configuration.

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 arises 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 depart from strict profit maximization. Another testable hypothesis is 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 with, or without, R&D spillovers. Further, a new strand of the literature that investigates strategic delegation under the prism of a multiple leader–follower model in an n-firm oligopoly, in which entrants consider different configurations of sales revenue delegation, deserves attention for further studies (see and Wang, 2009). In particular, it can shed more light to the question of how the degree and the type of competition may affect firms' R&D and their overall performance.

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Appendix

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 $c < \widehat{c}_\Pi(r)$.

By comparing equilibrium managerial incentive parameters in the Asymmetric Delegation configuration, given by (19) and (20), 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 (21)), it can be checked that $x_1^A > x^{FD} > x^{PD} > x_2^A$ always. Turning to equilibrium outputs and profits (see (21) and (22)), 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.

Proof of Proposition 3

(i) The (FD, FD) candidate equilibrium: We only need to consider one deviation. Let owner i follow an FD strategy and set the incentive parameter a^{FD}. Owner j will follow the same strategy and obtain profits Π^{FD} only if he does not have incentive to switch to a PD strategy and postpone the incentive parameter choice for Stage 3. The deviation game unravels as follows. Given owner i's choice of a^{FD} in Stage 1, R&D decisions are taken by manager i and owner j in Stage 2. Then owner j sets the incentive parameter for his manager in Stage 3 and finally firms' managers choose outputs. 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 i sets $a_i = a^{FD}$. By substituting $a_i = a^{FD}$ into (18), and using (16), (4) and (1), the deviant firm j's profits turn out to be:

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

It is then easy to check that $\Pi_j^d \leq \Pi^{FD}$ if and only if $c \geq \overline{c}_{FD}(r)$, 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 $c \geq \overline{c}_{FD}(r)$, (FD, FD) is an equilibrium configuration.

(ii) The (PD, PD) candidate equilibrium: Again we need to consider only one deviation. If owner j expects that owner i will follow a PD strategy and choose the incentive parameter for his manager in Stage 3, he will follow the same strategy and obtain Π^{PD} profits only if he does not have incentive to switch to an FD strategy and set the incentive parameter for his manager in Stage 1. In this case, the deviation game unravels as follows. In Stage 1, owner j sets a_j, and in Stage 2, manager j and owner i chose their firms' R&D expenditures. In Stage 3, owner i sets a_i, and in the final stage managers engage in output competition. Clearly, the deviation game is the same as the asymmetric delegation configuration game with $j = 1$ and $i = 2$. This is so because owner i knows the whole history of actions (a_1, x_1, x_2) while setting a_i and, moreover, owner j anticipates that owner i will optimally react to this history. An immediate consequence of Proposition 1(iv) is that $\Pi_j^d = \Pi_1^A > \Pi^{PD}$; hence, (PD, PD) is never an equilibrium configuration.

(iii) The (FD, PD) candidate equilibrium: Here we need to consider two deviations using similar reasoning as above. In brief, first, owner 1 may deviate from an FD to a PD strategy; and second, owner 2 may deviate from a PD to an FD strategy. The first deviation game unravels as follows. In stage 1, there is no action. In Stage 2, owners choose their firms' R&D expenditures, in Stage 3 they set their managers' incentive parameters and in Stage 4 managers choose output. Clearly, this deviation game is identical to the Universal Partial Delegation game. Since owner 1 takes no action in Stage 1, it becomes common knowledge that he will set the incentive parameter in Stage 3. Proposition 1(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 thus set the managerial incentive parameter in Stage 3. However, the deviant owner 2 sets instead the incentive parameter for his manager in Stage 1, optimally responding to a_1^A. Then in stage 2, 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.[32] It can be then checked that $\Pi_2^d \leq \Pi_2^A$ if and only if $c \leq \overline{c}_A(r)$, 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.

Proof of Proposition 4 Total welfare under Universal Full Delegation, Universal Partial Delegation, Asymmetric Delegation configuration and Non-Delegation are given by the following expressions, respectively:

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

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

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

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

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 strategic use of managerial incentive contracts has been introduced by Vickers (1985), Fershtman (1985), Fershtman and Judd (1987) and Sklivas (1987) (or the VFJS model). In these papers, each firm's owner has the option 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 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). For instance, 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). See Jansen et al. (2009), Manasakis et al. (2010), and Wang and Wang (2010), for other delegation schemes used in different industries.

[4]Another important branch of the delegation literature assumes away strategic interactions and focusses instead on agency issues. In contrast to the strategic delegation literature, the managers' incentives schemes here are linked to profit maximization (e.g., Milkovich et al. 1991; Metcalf and Simpson 2009). Such a link, however, may induce managers to avoid high-risk R&D investments and may, thus, decrease firms' innovation activities (see, Baysinger et al. 1991; Hoskisson et al. 1991; Eisenmann 2002; Makri et al. 2006).

[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]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).

[7]See for instance, Makri et al. 2006; Metcalf and Simpson 2009; Eisenmann 2002; Milkovich et al. 1991; Baysinger et al. 1991; Hoskisson et al. 1991. Gürtler (2008), in a principal agent model, analyzes 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).

[8]Kopel and Riegler (2006) amend the solution of Zhang and Zhang (1997), indicating that due to computational mistakes, some of their results do not hold.

[9]A related strand of the literature considers strategic delegation focusing on different types of long-run firms' decisions. For instance, Barcena-Ruiz and Casado-Izaga (2005) examine location decisions under price competition, while Tomaru et al. (2011) examine capacity choice.

[10]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. See Amir et al. (2010) and Röller and Sinclair-Desgagni (1996) for an excellent review.

[11]In the basic model we assume away R&D spillovers. In section 7, in the spirit of Zhang and Zhang (1997) and Kopel and Riegler (2006, 2008), we study the impact of R&D spillovers on our main results.

[12]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.

[13]As is common practice in the strategic delegation literature, moral hazard issues that may arise in this context are ignored. The emphasis is instead put on strategic interactions aspects that are rending 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).

[14]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.

[15]The assumption of risk neutral managers is standard in the strategic delegation literature (See for instance, Vickers1985; Fershtman 1985; Fershtman and Judd 1987; Sklivas 1987; and Miller and Pazgal 2001, 2002, 2005). In contrast to risk-neutral managers, risk-averse managers react less to the incentives set by the owners, i.e.,

they stick to a behavior closer to profit maximization. Then owners have lower ability to manipulate their managers by using appropriate incentive schemes.

[16]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. These values are then selected in such a way that the manager´s participation constraint is satisfied.

[17]For a related analysis regarding Partial delegation, see also Lambertini and Primavera (2001) and Loffler (2011).

[18]An owner could delegate only the R&D decision to his manager, keeping the output decision for himself. However, this alternative Partial Delegation strategy turns out to be strictly dominated by the Full Delegation strategy and thus never arises in equilibrium (The proof is available from the authors upon request). To keep the analysis as simple as possible, we do not include this alternative PD strategy in the basic model.

[19]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).

[20]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. Note that (N, N) is a special case of Qiu (1997).

[21]The analysis here is as a special case of Kopel and Riegler (2008) with no R&D spillovers.

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

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

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

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

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

[27]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.

[28]This solution approach is the only appropriate because the owners' best response functions are discontinuous in the basic game. For instance, if owner i has chosen an FD strategy with an incentive parameter a_i^{FD}, the best response of owner j is *either* to follow an FD strategy with $a_j^{FD} = R_a(a_i^{FD})$, *or take no action* at this stage. The latter is equivalent to owner j switching to a PD strategy and thus setting his incentive parameter optimally in Stage 3, given a_i^{FD} and the implied from the strategy profile (a_i^{FD}, no action) firms' R&D investments in Stage 2.

[29]To avoid corner solutions we assume that $\gamma < 0.85$, i.e., that the two goods are not too close substitutes.

[30]We have also considered the case in which firms produce differentiated products under output competition. For a detailed analysis of this case see Mitrokostas and Petrakis (2011).

[31]The detailed analysis is available from the authors upon request.

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

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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}

Table 2: Simulation results for Proposition 1 under R&D spillovers (θ)

$\theta = .05$			
a_1^A =0.59101	a_2^A =0.84206	a^{FD} =0.78546	a^{PD} =0.77840
x_1^A =0.04079	x_2^A =0.01502	x^{FD} =0.02729	x^{PD} =0.02438
q_1^A =0.28825	q_2^A =0.15254	q^{FD} =0.20992	q^{PD} =0.21024
Π_1^A =0.02071	Π_2^A =0.01050	Π^{FD} =0.01911	Π^{PD} =0.01912
$\theta = .5$			
a_1^A =0.61772	a_2^A =0.82141	a^{FD} =0.78180	a^{PD} =0.77876
x_1^A =0.01853	x_2^A =0.01438	x^{FD} =0.02112	x^{PD} =0.01680
q_1^A =0.26844	q_2^A =0.17014	q^{FD} =0.21129	q^{PD} =0.21008
Π_1^A =0.02167	Π_2^A =0.01214	Π^{FD} =0.02082	Π^{PD} =0.02065
$\theta = .95$			
a_1^A =0.68628	a_2^A =0.81290	a^{FD} =0.76940	a^{PD} =0.78526
x_1^A =0.00280	x_2^A =0.01223	x^{FD} =0.01487	x^{PD} =0.00911
q_1^A =0.24262	q_2^A =0.18152	q^{FD} =0.21254	q^{PD} =0.20710
Π_1^A =0.02186	Π_2^A =0.01572	Π^{FD} =0.02098	Π^{PD} =0.02103

Figure 1: Emerging Equilibria under no commitment.