Relative Performance Evaluation and Contract Externalities*

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Abstract

We consider the incentive characteristics of optimal linear contracts based on relative performance evaluation (RPE) for managers under moral hazard in imperfectly competitive product markets. Each contract influences the quantity choices of all competing agents causing contract externalities that affect the principals' contracting game. We analyze the relations between the optimal extent of RPE and several firm and market characteristics, especially allowing for heterogeneous firm characteristics and imperfectly correlated firm profits. We find non-monotonic comparative static results, which yield an explanation for the mixed empirical results in the literature and may help to improve the empirical evidence regarding RPE.

Keywords: contract externalities, managerial incentives, product market competition, relative performance evaluation

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1 Introduction

This paper explores contract externalities that arise in a single-period setting with two principal/agent-relations. In this setting, each principal contracts separately with his agent to supply personally costly effort and to choose the quantity of the product to be sold on the market. While the effort choices are independent, the two firms face Cournot competition on the product market. Given that market decisions are interdependent, and assuming that the contract influences the agent's quantity choice, this contract also influences the quantity choice of a rival firm's agent. Then, two kinds of contract externalities arise: first, the choices of the rival firm's agent may influence the performance measures that are used to evaluate one's agent, and, second, these choices may influence the expected net payoff to the principal. In equilibrium, these contract externalities are considered in the contracting game played by the principals.

We examine the consequences of contract externalities for the principal's choice of using relative performance evaluation (RPE).[1] RPE serves two different roles. First, by filtering out systematic risk from an agent's compensation, RPE results in stronger effort incentives (Holmström (1982)). For example, if firm profits in an industry are positively correlated, choosing a positive weight on own firm profit and a negative weight on the rival firm's profit filters out some of the industry's systematic risk and, thus, yields stronger effort incentives. Second, RPE influences an agent's product market decision and, thus, serves as a strategic commitment device (Vickers (1985)). Then, by including the rival's performance into an agent's compensation scheme, RPE may soften or strengthen the agent's aggressiveness in oligopolistic competition. Thus, the paper addresses Bushman/Smith's (2001) call for research on the impact of competition on RPE.

A broad literature empirically tests for the implications of RPE[2] by statistically regressing compensation on firm and industry performance. These studies yield mixed results. Basically, the evidence of RPE differs substantially across industries. For example, considering

[1] We refer to the principal using RPE if he assigns a non-zero incentive weight to the performance of a peer group. However, RPE is often defined as a negative weight on the performance measure. See, for example, Aggarwal/Samwick (1999).

[2] Antle/Smith (1986), Barro/Barro (1990), Jensen/Murphy (1990), Gibbons/Murphy (1990), Janakiraman/Lambert/Larcker (1992), Aggarwal/Samwick (1999), Joh (1999) and Murphy (1999) are some often cited examples.

US commercial banks, Barro/Barro (1990) provide evidence contradicting RPE. On the other hand, considering US manufacturers, Aggarwal/Samwick (1999) observe a positive relation between compensation and industry performance. Moreover, Albuquerque (2005) provides evidence for RPE using stock returns based on industry peer groups of similar sized firms in the US. We suppose that these mixed results follow from an omitted firm and industry effect on contract design. This conjecture corresponds with several empirical studies that find evidence of a link between an industry's competitiveness and managerial incentives. For example, Funk/Wanzenried (2003) observe countervailing effects of competitiveness on incentive schemes. Cuñat/Guadalupe (2005) consider the appreciation of the British pound in 1996 as a quasi-natural experiment for an unexpected change in competition, and find that more competitiveness leads to an increase in pay-for-performance sensitivity. Karuna (2005) supports this result by finding that firms in more (less) competitive industries use stronger (weaker) incentives.

In a setting with two principal/agent-relations, we assume that each principal contracts with his agent to supply personally costly effort and to make a product market choice. Due to the product market, the agents' quantity choices, and, therefore, the principals' contracting choices are interdependent. As a consequence, we find, in general, non-monotonic comparative static results with respect to the relevance of RPE and agent risk tolerance, industry competitiveness, the correlation of firm profits, and systematic risk. Moreover, because of the externalities, market size and firm-specific risk influences the relevance of RPE.

Key to our results is the relative importance of the net payoff from the agent's effort, and the net payoff from selling the product. For example, consider the impact of systematic risk with imperfectly correlated firm profits. For both a zero systematic risk and an infinitely systematic risk, filtering systematic risk from the agent's compensation is either irrelevant or impossible. Hence, the principal chooses the weight for the rival's profit in the agent's performance evaluation such as to maximize the expected net payoff from product market competition. On the other hand, given intermediate values of systematic risk and depending on the payoff productivity of the agent's action, a different incentive weight is beneficial to the principal. Specifically, given a negligible expected net payoff from product market competition, the principal chooses the incentive weight for the rival's firm profit such as to maximize the expected net payoff from the agent's effort choice. In general, an ambiguous relation between the incentive weight and the systematic risk results. Finally, given perfectly correlated firm profits and a sufficient productivity of the agent's effort, a complete filtering of systematic risk is feasible and beneficial to the principal. Thus, only for the latter special case, a monotonic relation between the incentive weight on the rival's firm profit and systematic risk results.

Likewise, in general, ambiguous relations between the industry's competitiveness, the correlation of firm profits, and the incentive weight for the rival's firm profit result. However, unambiguous relations may result (a) if one component of firm profit, i.e., the net payoff from the agent's effort choice or the net payoff from the product market, dominates, and (b) if the firms are identical. Finally, it is straightforward that the use of RPE may increase the expected net payoff to the principal. Key to this result is that RPE is (weakly) beneficial due to the filtering of systematic risk, and is potentially beneficial by properly altering the agent's aggressiveness in product market competition.

Several implications for empirical studies testing for RPE follow from the analysis. First, assuming that the payoff from the product market correlates negatively with the industry's competitiveness, the competitiveness has a substantial impact on the weight for the rival's firm profit, i.e., the relevance of RPE. However, the relation between the industry's competitiveness and the relevance of RPE is non-monotonic. Second, the relation between the relevance of RPE and the correlation of firms' profit is ambiguous. Due to the ambiguous relations, a simple cross sectional analysis has a bias towards not detecting RPE.

The remainder of this section reviews the related literature. Section 2 describes the model and derives general properties of optimal linear incentive schemes based on RPE. Section 3 examines the impact of several parameters on the use of RPE. Due to complexity inherent in the problem, we base our analysis on numerical examples and closed form solutions for some special cases. In Section 4 we draw some conclusions and outline implications for empirical studies.

1.1 Previous Research

Segal (1999) and Genicot/Ray (2006) consider contract externalities in a setting where a principal contracts with multiple agents. Our analysis differs in that we consider a setting where a different principal contracts with each agent, and we analyze the principals' contracting choices that arise in Nash equilibria.

Several papers discuss the effects of competition on managerial slack and, thus, on managerial incentives. For example, Schmidt (1997) shows that the influence of competition on managerial incentives is ambiguous, since competition lowers the probability of liquidation for firms with managerial slack, while it also reduces firm profits.[3]

Another stream of the literature focuses on strategic delegation in oligopolies, without explicitly considering a moral hazard problem. Following Schelling (1960), in a non-cooperative game, delegation of a decision may improve the principal's expected net benefit if the relevant (or the imposed) objectives of the delegatee differ substantially from his own preferences. Within different oligopoly settings, Fershtman (1985), Vickers (1985), Fershtman/Judd (1987), Sklivas (1987), Reitman (1993), and Miller/Pazgal (2002) show that evaluating the agent relative to a measure of the competitor's performance, e.g., the rival's profit, sales, or market share, serves as a strategic commitment device, alters the agent's aggressiveness in market competition, and, ultimately, may improve firm profits.[4] Due to the externalities, the agent's performance evaluation crucially depends on the firm's and its competitor's product market competition.[5]

Finally, Fumas (1992) and Aggarwal/Samwick (1999) address Vickers' (1985, p. 145) statement: "In a setting with many interdependent principal-agent pairs, payments according to relative performance may therefore have strategic, as well as informational, advantages." These papers consider a setting with two principal/agent-relations, where each agent supplies personally costly effort, the two firms compete in a duopoly, and the product market choice is delegated to the agent. Here, the two principals may use RPE to filter out systematic risk and, thus, provide stronger effort incentives. Although the agents have no direct preferences regarding the product market decision, their choices influence the performance measures included in their compensation schemes, i.e., the firm's own profit and the rival's profit. As a

[3]See also Hart (1983), Scharfstein (1988), and Hermalin (1992).

[4]Bagwell (1995) fundamentally criticizes the effects of strategic delegation. In a sequential move game, he shows that any commitment effect may disappear if a marginal uncertainty concerning the commitment signal exists. Huck/Müller (2000), however, find no evidence for Bagwell's result in experiments.

[5]Given risk neutral agents, Miller/Pazgal (2001) show that the use of RPE yields equivalent firm profits for Bertrand and Cournot competition.

consequence, the agents' product market choices are the result of induced moral hazard.[6] Consequently, the principals' choices regarding the agents' incentive compensation reflect the impact on the agents' effort choices and product market decisions.

Fumas (1992) examines properties of equilibria in a general framework with heterogeneous firms in differentiated Cournot and Bertrand competition. Assuming a perfect positive correlation of firm profits, he shows that with Cournot competition and risk averse agents, a unique equilibrium results, and both principals choose a negative weight on the rival's profit. With Bertrand competition, however, the sign of the incentive weight is ambiguous.[7]

Based on a stylized product market model with specific demand and cost functions for identical firms, Aggarwal/Samwick (1999) derive monotonic comparative static results for differentiated Bertrand and Cournot competition. They assure that their "theoretical results continue to hold in a fully specified principal-agent model"[8], i.e., a setting characterized by moral hazard. Assuming that firm profits are perfectly positive correlated, they find that in a setting with moral hazard and differentiated Bertrand competition the optimal contract puts a positive weight on own and rival's profit, whereas under Cournot competition the weight on the rival's profit is negative. Testing their model's predictions, Aggarwal/Samwick (1999) find weak evidence for a positive relation between compensation and industry performance, and thus, reason that their empirical results support solely the Bertrand case.[9] However, we find that their results only hold true for the special case of a perfect positive correlation of firm profits. That is, given imperfectly correlated firm profits, non-monotonic comparative statics result. Then, the relation between the incentive weight placed on the rival firm's profit and the firm's systematic risk, the industry's competitiveness, and the correlation of firm profits, is ambiguous.

Finally, Aggarwal/Samwick (1999) conclude that, in general, RPE is detrimental to each principal. Again, their result only holds true for the special case of a perfect positive cor-

[6] See, e.g., Christensen/Feltham (2005), pp. 201-210.

[7] Graziano/Parigi (1998) and Merzoni (2000) consider a related setting with Cournot competition and incomplete information regarding marginal costs. Graziano/Parigi (1998) find a positive relation between the degree of product differentiation and the agent's effort as well as the agent's incentive rate. Assuming identical firms, Merzoni (2000) finds that strategic delegation increases the agent's effort level.

[8] Aggarwal/Samwick (1999), p. 2030.

[9] However, alternative effects may explain their empirical findings. For example, Oyer (2004) argues that, given a positive correlation between industry performance and executives' outside opportunities, compensation will be positively correlated to industry performance.

relation. Key to this result is the relative importance of the payoffs from the agent's effort choice and from the product market choice. That is, no prisoner's dilemma exists if, for both principal/agent-relations, the payoff from the agents' effort dominates, such that both principals choose the incentive weight for the rival's profit in order to minimize the incentive risk imposed on the agent. Therefore, given a sufficiently negative correlation, using RPE to reduce incentive risk results in a positive incentive weight for the rival firm's profit, thus reducing both agents' aggressiveness in product market competition, yielding an increase in the expected net payoff to both principals.

2 Basic Notation and Model Structure

2.1 Actions, Reports, and Preferences

We consider two firms in an industry characterized by differentiated Cournot competition. Principal i of firm i contracts separately with agent i, $i = 1, 2$. At date $t = 1$, both agents simultaneously choose their effort $a_i \in \mathbb{R}$ and the quantity $q_i \geq 0$ to be sold on the market, $i = 1, 2$. Both choices are non-contractible. Agent i's personal cost of effort is assumed to be

$$\kappa_i(a_i) = 1/2a_i^2\,, \quad i = 1, 2\,,$$

and we assume that he has no direct preferences regarding the product market choice. With heterogeneous firms, prices as functions of quantities[10] are

$$p_i(q_i, q_\ell) = \alpha_i - \beta_i q_i - \gamma_i q_\ell, \qquad i, \ell = 1, 2\,, \text{ and } i \neq \ell\,,$$

with $\alpha_i > 0$, $\beta_i > 0$, and $\gamma_i > 0$, i.e., the products are supposed to be substitutes. We define the firms to be identical if the parameters of the inverse demand function and the parameters of the principal's payoff are the same. We assume that product i's saturation quantity is

[10] The inverse demand system is based on consumer preferences. For example, consider the special case of identical consumers and $\gamma_1 = \gamma_2 = \gamma$. A representative consumer maximizes his utility $U(q_1, q_2) = \alpha_1 q_1 + \alpha_2 q_2 - 1/2(\beta_1 q_1^2 + \gamma q_1 q_2 + \beta_2 q_2^2) - p_1 q_1 - p_2 q_2$, with $\alpha_i > 0$, $\beta_i > 0$, $p_i > 0$, $i = 1, 2$, and $\beta_1 \beta_2 > \gamma^2$ to ensure strict concavity. Then, the first order conditions for the consumer's optimal quantity choices define the indirect demand system. See, e.g., Vives (1999).

positive[11], i.e.,

$$q_i^0 = (\alpha_i\beta_\ell - \alpha_\ell\gamma_i)/(\beta_i\beta_\ell - \gamma_i\gamma_\ell) \geq 0, \quad i,\ell = 1,2, \text{ and } i \neq \ell\,.$$

Finally, we use the sum of the saturation quantities as a measure for market size s, i.e., $s = q_1^0 + q_2^0$.

At date $t = 2$ the firms' profits x_i are publicly disclosed. We assume that the payoff from the agent's effort and the payoff from the product market competition are additively separable. Hence, the agent's effort may be interpreted as a reduction of the firm's fixed costs. Moreover, principal i's payoff is linear in agent i's effort choice, i.e.,

$$x_i = b_i a_i + q_i(\alpha_i - \beta_i q_i - \gamma_i q_\ell - c_i) + \epsilon_i, \qquad i,\ell = 1,2\,, \text{ and } i \neq \ell,$$

where $b_i > 0$ is agent i's payoff productivity, and $c_i > 0$ is product i's marginal cost. The noise terms ϵ_i, $i = 1,2$ are assumed to be normally distributed with $\epsilon_i \sim \mathrm{N}(0,\sigma_i^2)$ and $\mathrm{Cov}[\epsilon_1,\epsilon_2] = \rho\sigma_1\sigma_2$. Finally, to ensure an interior solution for the quantity choices, $\alpha_i - c_i > 0$, $i = 1,2$.

As is standard in the LEN model[12], we restrict the compensation paid to agent i at date $t = 2$ to be a linear function of the performance reports, i.e.,

$$w_i = f_i + \nu_i(x_i + \mu_i x_\ell), \qquad i,\ell = 1,2, \text{ and } i \neq \ell, \tag{1}$$

where f_i is agent i's fixed wage, and ν_i is the incentive rate for performance measure $x_i + \mu_i x_\ell$. The parameter μ_i shows the weight for the rival's profit in the agent's performance evaluation.[13] The absolute value $|\mu_i|$ indicates the extent to which agent i's compensation depends on RPE. The contract offered to agent i by principal i at date $t = 0$ is $z_i = (f_i,\nu_i,\mu_i)$, and $\mathbf{z} = (z_1,z_2)$. We assume an exogenous mechanism enforces both contracts.[14] Also, $\mathbf{z}$ is assumed to be common knowledge at $t = 1$, for example, due to mandatory disclosure of executive compensation.[15]

[11] With the saturation quantities q_i^0, prices $p_i(q_i^0,q_\ell^0)$ are equal to zero, $i = 1,2$. Given identical firms and homogeneous products, the saturation quantity is $q^0 = \alpha/\beta$.

[12] See Holmstrom/Milgrom (1987).

[13] Obviously, the contract characterized by (1) is equivalent to contract $w_i = f_i + \nu_{ii}x_i + \nu_{i\ell}x_\ell$, $i,\ell = 1,2$, and $i \neq \ell$. Hence, $\mu_i = \nu_{i\ell}/\nu_{ii}$ represents the incentive ratio of the incentive rates for the two performance reports.

[14] For example, in a repeated setting the contracts are supposed to be enforced by reputation effects.

[15] Since the contracts are common knowledge at $t = 1$, any changes by principal i prior to $t = 1$ are ineffective if principal $\ell \neq i$ has the possibility to respond. Renegotiations after $t = 1$, however, focus on efficient risk-sharing. Given a risk averse agent and a risk neutral principal, Fudenberg/Tirole (1990) establish that post-decision renegotiation removes any effort incentives.

The agents' preferences are represented by negative exponential utility functions, with

$$u_i = -\exp\{-r_i(w_i - \kappa_i(a_i))\}, \qquad i = 1, 2,$$

where r_i is agent i's coefficient of absolute risk aversion. In this LEN-setting, agent i's certainty equivalent given contracts $\mathbf{z}$, and his conjectures $\hat{a}_\ell$ and $\hat{q}_\ell$ with respect to the other agent's choices, is

$$\begin{aligned} CE_i(\mathbf{z}, a_i, \hat{a}_\ell, q_i, \hat{q}_\ell) &= \mathrm{E}[w_i|\mathbf{z}, a_i, \hat{a}_\ell, q_i, \hat{q}_\ell] - \kappa_i(a_i) - 1/2 r_i \,\mathrm{Var}[w_i|\mathbf{z}] \\ &= f_i + v_i\left(\mathrm{E}[x_i|a_i, q_i, \hat{q}_\ell] + \mu_i \,\mathrm{E}[x_\ell|\hat{a}_\ell, q_i, \hat{q}_\ell]\right) \\ &\quad - 1/2 a_i^2 - 1/2 r_i v_i^2 \left(\sigma_i^2 + 2\mu_i \rho \sigma_i \sigma_\ell + \mu_i^2 \sigma_\ell^2\right). \end{aligned} \tag{2}$$

Of course, agent i will only participate in the firm if his contract z_i provides him with his reservation wage, which is scaled to zero, i.e.,

$$CE_i \geq 0, \qquad i = 1, 2. \tag{3}$$

Principal i is risk neutral. His expected net payoff consists of the gross payoff x_i realized at date $t = 2$ minus the expected compensation paid to his agent, i.e.,

$$\Pi_i = \mathrm{E}[x_i - w_i|\hat{a}_i, \hat{a}_\ell, \hat{q}_i, \hat{q}_\ell, \hat{z}_\ell], \qquad i, \ell = 1, 2, \text{ and } i \neq \ell. \tag{4}$$

2.2 Optimal Agents' Choices

Differentiating (2) with respect to a_i given contracts $\mathbf{z}$ and conjectures $\hat{a}_\ell$ and $\hat{q}_\ell$, provides the following characterization of agent i's effort choice

$$a_i^\dagger(v_i) = b_i v_i, \qquad i = 1, 2. \tag{5}$$

The key to the independence of the agents' effort choices is that the marginal effort cost and the marginal expected compensation are independent of the other agent's effort choice, and that the variance of the compensation is independent of the agents' effort choices. Thus, the individually optimal effort choices constitute a single Nash equilibrium (consisting of dominant effort choices).

Next, differentiating (2) with respect to q_i given contracts $\mathbf{z}$, and conjectures $\hat{a}_\ell$ and $\hat{q}_\ell$, provides the reaction function of agent i to agent ℓ's quantity choice, i.e.,

$$q_i^r(\mu_i, \hat{q}_\ell) = \frac{\alpha_i - c_i}{2\beta_i} - \frac{\gamma_i + \gamma_\ell \mu_i}{2\beta_i}\, \hat{q}_\ell\,, \qquad i, \ell = 1, 2, \text{ and } i \neq \ell. \tag{6}$$

While agent i has no direct preferences regarding the product-market choice q_i, his quantity choice is subject to an induced moral hazard problem[16]. If principal i pays agent i a fixed wage, the agent will implement any quantity q_i chosen by the principal. On the other hand, while a non-zero incentive rate $v_i \neq 0$ is sufficient to induce direct preferences regarding the product market choice, agent i's quantity choice is only influenced by the incentive weight μ_i for the rival's firm profit, and the conjecture $\hat{q}_\ell$ regarding the other agent's quantity choice.

The solution in (6) indicates that with RPE, the principal may fundamentally alter his agent's aggressiveness in product market competition. In general, agent i's aggressiveness is given by his reaction to the other agent's anticipated quantity choice, i.e.,

$$\frac{\partial q_i^r(\mu_i, \hat{q}_\ell)}{\partial \hat{q}_\ell} = -\frac{\gamma_i + \gamma_\ell \mu_i}{2\beta_i}, \qquad i, \ell = 1, 2, \text{ and } i \neq \ell,$$

and his aggressiveness increases if for every $\hat{q}_\ell$ agent i responds with a greater q_i. Assume that the products are substitutes, i.e., $\gamma_i > 0$, $i = 1, 2$. Figure 1 illustrates that $\mu_i > 0$ results in a less steep reaction function as compared to $\mu_i = 0$, thereby softening agent i's aggressiveness. More specifically, since $\gamma_i + \gamma_\ell \mu_i > 0$ for $\mu_i > 0$, agent i lowers his quantity choice q_i if he expects agent ℓ to increase q_ℓ. For a given quantity $\hat{q}_\ell$, increasing μ_i results in a lower quantity q_i, i.e., a less aggressive response to agent ℓ's quantity choice. On the other hand, for $\mu_i \in (-\gamma_i/\gamma_\ell, 0)$, the reaction function is steeper as compared to $\mu_i = 0$. Within the interval, decreasing μ_i results in a more aggressive response to $\hat{q}_\ell$. Moreover, for $\mu_i = -\gamma_i/\gamma_\ell$, agent i behaves as if he were a monopolist, i.e., his quantity choice is independent of agent ℓ's quantity choice. Finally, for $\mu_i < -\gamma_i/\gamma_\ell$, agent i reacts as if the products were complements, and decreasing μ_i results in an even more aggressive reaction. Then, because of the positive slope of the reaction function, agent i increases quantity q_i if he expects agent ℓ to increase quantity q_ℓ, and his reaction increases with μ_i.

———— Insert Figure 1 here ————

[16]See, for instance, Demski/Sappington (1987), and Christensen/Feltham (2005), pp. 201-210.

In equilibrium, each agent's conjecture is equal to the other agent's quantity choice. Thus, solving (6) yields the optimal quantity choices as specified in Proposition 1.

Proposition 1: Given exogenously specified compensation contracts $\mathbf{z}$, there exists a single Nash equilibrium, and the agents' optimal quantity choices are characterized by

$$q_i^\dagger(\mu_i, \mu_\ell) = \frac{2(\alpha_i - c_i)\beta_\ell - (\alpha_\ell - c_\ell)(\gamma_i + \gamma_\ell \mu_i)}{4\beta_i\beta_\ell - (\gamma_i + \gamma_\ell\mu_i)(\gamma_\ell + \gamma_i\mu_\ell)} \tag{7a}$$

$$\text{with} \quad 4\beta_i\beta_\ell \neq (\gamma_i + \gamma_\ell\mu_i)(\gamma_\ell + \gamma_i\mu_\ell)\,, \qquad i, \ell = 1, 2, \text{ and } i \neq \ell\,. \tag{7b}$$

In equilibrium, since q_ℓ^r is influenced by μ_ℓ, $q_i^\dagger$ is influenced by both weights μ_i and μ_ℓ for the rival's firm profit in both contracts, $i, \ell = 1, 2$, and $i \neq \ell$. Thus, by evaluating agent i's performance relative to the performance of competitor $\ell \neq i$, principal i influences his own agent's quantity choice plus the quantity choice of the competitor's agent. Hence, there are externalities to contracting with agent i. Note that condition (7b) restrains the feasible set of parameters to rule out parameter combinations that yield parallel reaction functions, i.e., to avoid a zero denominator in (7a).[17]

Corollary 1: The solution to (7a) has the following properties:

(a) Agent i's quantity choice increases in the incentive weight μ_i chosen in his compensation contract for the rival's firm profit

(i) if $\gamma_\ell > 0$ and $\mu_\ell > (2\beta_i(\alpha_\ell - c_\ell)/(\alpha_i - c_i) - \gamma_\ell)/\gamma_i$, and

(ii) if $\gamma_\ell < 0$ and $\mu_\ell < (2\beta_i(\alpha_\ell - c_\ell)/(\alpha_i - c_i) - \gamma_\ell)/\gamma_i$,

and it decreases for all other strict relations ($i, \ell = 1, 2,$ and $i \neq \ell$).

(b) Agent i's quantity choice increases in the incentive weight μ_ℓ chosen in the compensation contract of the competitor's agent

(i) if $\gamma_i > 0$ and $-\gamma_i/\gamma_\ell < \mu_i < (2\beta_\ell(\alpha_i - c_i)/(\alpha_\ell - c_\ell) - \gamma_i)/\gamma_\ell$,

(ii) if $\gamma_i < 0$ and $\mu_i < -\gamma_i/\gamma_\ell$, and

(iii) if $\gamma_i < 0$ and $(2\beta_\ell(\alpha_i - c_i)/(\alpha_\ell - c_\ell) - \gamma_i)/\gamma_\ell < \mu_i$,

[17] Thus, given homogenous products, (7b) excludes $\mu_1 = \mu_2 = 1$. Moreover, we focus our analysis to situations characterized by positive quantities in equilibrium. Thus, we implicitly restrict the feasible set of compensation parameters by the condition $q_i^\dagger \geq 0$, $i = 1, 2$.

and it decreases for all other strict relations ($i, \ell = 1, 2,$ and $i \neq \ell$).

In general, the equilibrium relation between $q_i^\dagger$, $i = 1, 2$, and μ_1 and μ_2, i.e., the impact of RPE on the quantity choice, is ambiguous. Assume that the products are substitutes, i.e., $\gamma_i > 0$, $i = 1, 2$. Then, increasing μ_i, i.e., softening agent i's aggressiveness, increases this agent's quantity choice $q_i^\dagger$ if μ_ℓ is larger than the threshold given by Corollary 1 (a) (i), i.e., if the competitor intensely uses RPE. On the other hand, increasing μ_ℓ, i.e., softening the aggressiveness of the competitor's agent, results in a larger quantity choice of agent i if μ_i lies within the interval as given by Corollary 1 (b) (i), i.e., if agent i is not too intensely evaluated relative to the competitor's agent.

2.3 Optimal Linear Contracts

2.3.1 Optimal Contract Choices

We assume firstly that the agent's action choices are contractible.[18] Then, no incentive risk is necessary to induce the agents to supply a desired effort level, and principal i chooses effort a_i and quantity q_i, $i = 1, 2$. Hence, the principal's objective is to maximize

$$\Pi_i = \mathrm{E}[x_i | a_i, \hat{a}_\ell, q_i, \hat{q}_\ell, \hat{z}_\ell] - 1/2 a_i^2, \qquad i, \ell = 1, 2, \text{ and } i \neq \ell. \tag{8}$$

In equilibrium, principal i's conjectures are identical to the choices made by the other participants. From the first order conditions we directly establish that the action choices and principal i's net payoff are

$$a_i^* = b_i\,, \tag{9a}$$

$$q_i^* = \frac{2(\alpha_i - c_i)\beta_\ell - (\alpha_\ell - c_\ell)\gamma_i}{4\beta_i\beta_\ell - \gamma_i\gamma_\ell}\,, \text{ and} \tag{9b}$$

$$\Pi_i^* = \frac{b_i^2}{2} + \frac{\beta_i(2(\alpha_i - c_i)\beta_\ell - (\alpha_\ell - c_\ell)\gamma_i)^2}{(4\beta_i\beta_\ell - \gamma_i\gamma_l)^2}\,, \qquad i, \ell = 1, 2, \text{ and } i \neq \ell\,. \tag{9c}$$

[18]While standard agency theory refers to this as the first-best setting, considering strategic delegation and following Katz (2006) we refrain from using the terminology of first best vs. second best.

Note that due to the assumptions of the LEN-model, the principal's net payoff is perfectly separable into a net payoff from the agent's effort choice and a payoff from product market competition.

Next, consider non-contractible agents' actions. Then, each principal chooses compensation parameters z_i such as to maximize (4) subject to incentive constraints (5) and (7a), and participation constraint (3). Choosing f_i such that $CE_i = 0$, substituting f_i and (5) into (4) yields principal i's unconstrained optimization problem, i.e.,

$$\max_{\nu_i,\mu_i} \Pi_i = \Pi_i^e(\nu_i,\mu_i) + \Pi_i^m(\mu_i,\hat{\mu}_\ell), \qquad i,\ell = 1,2, \text{ and } i \neq \ell, \tag{10a}$$

with

$$\Pi_i^e(\nu_i,\mu_i) = b_i^2\nu_i - \frac{1}{2}b_i^2\nu_i^2 - \frac{r_i}{2}\nu_i^2\left(\sigma_i^2 + 2\mu_i\rho\sigma_i\sigma_\ell + \mu_i^2\sigma_\ell^2\right), \tag{10b}$$

$$\Pi_i^m(\mu_i,\hat{\mu}_\ell) = q_i^\dagger(\mu_i,\hat{\mu}_\ell)[\alpha_i - \beta_i q_i^\dagger(\mu_i,\hat{\mu}_\ell) - \gamma_i q_\ell^\dagger(\mu_i,\hat{\mu}_\ell) - c_i], \tag{10c}$$

where Π_i^e is principal i's net payoff from agent i's effort choice, Π_i^m is the net payoff from product market competition, and $q_i^\dagger$ is given by (7a), $i = 1,2$. Hence, we assume that the noise ϵ_i is completely due to measuring the agent's effort. In equilibrium, each principal's conjecture regarding the other principal's contract offer is identical to the actual contract choice, i.e., $\hat{z}_\ell = z_\ell$, $\ell = 1,2$. Thus, the first order conditions of (10a) yield necessary conditions for the optimal contract choices. Proposition 2 characterizes principal i's optimal choice of agent i's incentive contract.

Proposition 2: The optimal incentive weights are characterized by

$$\left.\frac{\partial\Pi_i^m(q_i,q_\ell)}{\partial q_i}\frac{\partial q_i(\mu_i,\hat{\mu}_\ell)}{\partial\mu_i} + \frac{\partial\Pi_i^m(q_i,q_\ell)}{\partial q_\ell}\frac{\partial q_\ell(\mu_i,\hat{\mu}_\ell)}{\partial\mu_i}\right|_{\hat{\mu}_\ell=\mu_\ell}$$

$$-r_i(\nu_i^\dagger)^2(\rho\sigma_i\sigma_\ell + \mu_i^\dagger\sigma_\ell^2) = 0, \tag{11a}$$

$$\nu_i^\dagger(\mu_i^\dagger) = \frac{b_i^2}{b_i^2 + r_i\left(\sigma_i^2 + 2\rho\mu_i^\dagger\sigma_\ell\sigma_i + (\mu_i^\dagger)^2\sigma_\ell^2\right)}, \qquad i,\ell = 1,2, \text{ and } i \neq \ell. \tag{11b}$$

Thus, the optimal contract parameters $\nu_i^\dagger$ and $\mu_i^\dagger$ are the simultaneous solution to (11a) and (11b), with $\Pi_i^m(q_i,q_\ell)$ according to (10c), and q_i according to (7a), $i,\ell = 1,2$ and $i \neq \ell$. Due to the complexity inherent in (11a) and (11b), closed form solutions are hard to find.[19] Moreover,

[19]These are based on the solution to a non-linear system of equations containing polynomials of higher order in μ_i and μ_ℓ. For example, given identical firms, this system is a single polynomial of fifth order in μ.

because of the non-linear relations given by (11a) and (11b), multiple Nash equilibria may result for the principal's contract choices.

2.3.2 Segregated Contract Choices

Now, consider the contract choices ν_i and μ_i that maximize the segregated net profits, i.e., the net payoff $\Pi_i^e(\nu_i, \mu_i)$ from the agent's effort choice, and the net payoff $\Pi_i^m(\mu_i, \hat{\mu}_\ell)$ from the product market competition. Lemma 1 characterizes these segregated contract choices.

Lemma 1: In equilibrium, the optimal contract choices ν_i and μ_i for the segregated net profits are

(a) for the net payoff from the agent's effort choice:

$$\nu_i^e = \frac{b_i^2}{b_i^2 + r_i(1-\rho^2)\sigma_i^2}, \tag{12a}$$

$$\mu_i^e = -\rho\frac{\sigma_i}{\sigma_\ell}, \qquad i, \ell = 1, 2, \text{ and } i \neq \ell. \tag{12b}$$

(b) for the net payoff from the product market competition:

$$\nu_i^m \neq 0, \tag{12c}$$

$$\mu_i^m = \frac{(\alpha_i - c_i)\beta_\ell\gamma_i - (\alpha_\ell - c_\ell)\gamma_i^2}{(\alpha_i - c_i)\beta_\ell\gamma_\ell - (\alpha_\ell - c_\ell)(2\beta_i\beta_\ell - \gamma_i\gamma_\ell)}, \qquad i, \ell = 1, 2, \text{ and } i \neq \ell\,. \tag{12d}$$

While the optimal μ_i^e regarding the agent's effort choice depends on the covariance and variance of the net profits, the optimal μ_i^m regarding the product market competition is driven by the characteristics of the demand functions. Obviously, in general, the two incentive weights μ_i^e and μ_i^m, $i = 1, 2$, differ.

With identical firms, Proposition 3 shows that the segregated solutions μ^e and μ^m define boundaries to the principals' choice $\mu^\dagger$ following (11a) and (11b).[20]

Proposition 3: With identical firms, the optimal compensation parameters for the segregated profits, i.e., μ^e and μ^m, define boundaries for the optimal incentive weight $\mu^\dagger$ for the

[20]Proposition 3 is proven in the appendix.

rival's firm profit in symmetric equilibria, i.e.,

$$\mu^\dagger \in (-\rho, -\frac{\gamma}{2\beta+\gamma}) \qquad \text{if } \rho > \frac{\gamma}{2\beta+\gamma}, \tag{13a}$$

$$\mu^\dagger = -\rho = -\frac{\gamma}{2\beta+\gamma} \qquad \text{if } \rho = \frac{\gamma}{2\beta+\gamma}, \text{ and} \tag{13b}$$

$$\mu^\dagger \in (-\frac{\gamma}{2\beta+\gamma}, -\rho) \qquad \text{if } \rho < \frac{\gamma}{2\beta+\gamma}. \tag{13c}$$

While closed form solutions for $z^\dagger$ are hard to find, Proposition 3 restricts the optimal incentive weight $\mu^\dagger$. With heterogeneous firms, however, optimal contract choices are, in general, asymmetric, and, hence, the solutions to the segregated profits do not establish boundaries for $\mu_i^\dagger$, $i = 1, 2$.

Proposition 3 indicates that with identical firms, and Cournot competition in substitutes, a positive correlation coefficient is a sufficient condition for a negative incentive weight, i.e., $\mu^\dagger < 0$ if $\rho > 0$. However, due to the joint effect of μ on the agent's effort and quantity choice, there does exist a threshold $\bar{\rho} < 0$ such that $\mu^\dagger < 0$ if $\rho \in (\bar{\rho}, 0)$. Therefore, the optimal incentive weight will only be positive if the correlation coefficient is sufficiently negative, i.e., $\mu^\dagger > 0$ if $\rho < \bar{\rho}$.

2.3.3 Relative Performance Evaluation and the Principal's Expected Net Payoff

We now consider the impact of RPE on each principal's expected net payoffs, i.e., whether RPE is beneficial to the principals. First, consider the principals' segregated contract choices with respect to product market competition. Given fixed wage contracts, i.e., $z_i^0 = (f_i, 0, 0)$, $i = 1, 2$, agent i is indifferent regarding quantity q_i. Due to the indifference, principal i chooses q_i. With the principal's choice as given by (9b), the expected net product market payoff to principal i is

$$\Pi_i^m(0,0) = \frac{\beta_i(2(\alpha_i - c_i)\beta_\ell - (\alpha_\ell - c_\ell)\gamma_i)^2}{(4\beta_i\beta_\ell - \gamma_i\gamma_l)^2}, \qquad i, \ell = 1, 2 \text{ and } i \neq \ell.$$

Note that fixed wage contracts z_i^0 are not a Nash equilibrium. Rather, the pair of weights (μ_1^m, μ_2^m) as given by (12d) constitute a Nash equilibrium regarding the principals' segregated contract choices. Then, principal i's expected net payoff is

$$\Pi_i^m(\mu_1^m, \mu_2^m) = \frac{(2(\alpha_i - c_i)\beta_\ell - (\alpha_\ell - c_\ell)\gamma_i)(2(\alpha_i - c_i)\beta_i\beta_\ell - (\alpha_\ell - c_\ell)\beta_i\gamma_i - (\alpha_i - c_i)\gamma_i\gamma_\ell)}{16\beta_i\beta_\ell(\beta_i\beta_\ell - \gamma_i\gamma_\ell)},$$

$$i, \ell = 1, 2 \text{ and } i \neq \ell. \tag{14}$$

It is straightforward to show that, for each principal, the payoff from product market competition with RPE is smaller than the payoff without RPE, i.e., $\Pi_i^m(\mu_1^m, \mu_2^m) < \Pi_i^m(0, 0)$, $i = 1, 2$. Therefore, considering the segregated contract choices with respect to product market competition, the principals face a prisoner's dilemma, i.e., they sustain a loss from evaluating the agent relative to the rival's profit. On the other hand, RPE is beneficial with respect to the expected net payoff from the agent's effort choice. That is, each principal benefits from filtering systematic risk from his agent's compensation, i.e., $\Pi_i^e(\nu_i^e, \mu_i^e) \geq \Pi_i^e(\nu_i, 0)$, for all $\nu_i \in \mathbb{R}$, $i = 1, 2$.

Therefore, considering the principals' contracting game that maximizes the firms' total expected profit $\Pi_i = \Pi_i^e(\nu_i^\dagger, \mu_i^\dagger) + \Pi_i^m(\mu_1^\dagger, \mu_2^\dagger)$, $i = 1, 2$, and in contrast to Aggarwal/Samwick (1999), it is straightforward that RPE may be beneficial to both principals. The simplest way to see this result is to consider noisy performance measures plus a sufficiently large payoff productivity for both agents. Then, the net payoff from the agent's effort choice with RPE exceeds the loss in the net payoff from product market competition. Hence, RPE is beneficial to both principals even though a prisoner's dilemma persists regarding the product market competition. Furthermore, given a negative correlation of firm profits plus a sufficiently large payoff productivity, the incentive weights $\mu_i^\dagger$, $i = 1, 2$, are non-negative, and the prisoner's dilemma regarding the product market competition disappears.[21] To summarize, whether RPE is beneficial or detrimental depends on the relevance of the agent's effort choice and the product market competition for the expected net payoff.

2.3.4 Relative Performance Evaluation and Optimal Effort Incentives

The discussion in Section 2.2 indicates that with μ_i, principal i influences his agent's aggressiveness in the product market competition. Moreover, due to the impact of μ_i on ν_i (see

[21] See Section 3.1 for some numerical examples.

(11b)), the extent of RPE also influences the agent's effort incentives. Likewise, agent i's effort incentives ν_i influence the optimal use of RPE.

Corollary 2: The solutions to (11a) and (11b) have the following properties:

$$\frac{\partial \nu_i^\dagger}{\partial \mu_i^\dagger} = -\frac{2b_i^2 r_i \sigma_l(\rho\sigma_i + \mu_i^\dagger \sigma_\ell)}{(b_i^2 + r_i(\sigma_i^2 + 2\rho\mu_i^\dagger \sigma_\ell \sigma_i + (\mu_i^\dagger)^2 \sigma_\ell^2))^2}, \tag{15a}$$

$$\frac{\partial \mu_i^\dagger}{\partial \nu_i^\dagger} = \frac{2r_i \nu_i \sigma_\ell(\rho\sigma_i + \mu_i \sigma_\ell)}{\frac{\partial}{\partial \mu_i}\left[\frac{\partial \Pi_i^m(q_i,q_\ell)}{\partial q_i}\frac{\partial q_i(\mu_i,\hat{\mu}_\ell)}{\partial \mu_i} + \frac{\partial \Pi_i^m(q_i,q_\ell)}{\partial q_\ell}\frac{\partial q_\ell(\mu_i,\hat{\mu}_\ell)}{\partial \mu_i}\Big|_{\hat{\mu}_\ell=\mu_\ell}\right] - r_i \nu_i^2 \sigma_\ell^2}, \tag{15b}$$

$i, \ell = 1, 2,$ and $i \neq \ell$.

According to (15a), $\nu_i^\dagger$ increases (decreases) with $\mu_i^\dagger$ if $\mu_i^\dagger < (>) -\rho\sigma_i/\sigma_\ell$. Therefore, an increase of $\mu_i^\dagger$, i.e., a softening of agent i's aggressiveness in the product market competition, may increase or decrease the incentive rate $\nu_i^\dagger$, i.e., may result in smaller or larger effort incentives. A sufficient condition for an unambiguous relation between $\nu_i^\dagger$ and $\mu_i^\dagger$ is $\rho\mu_i^\dagger > 0$, i.e., if the weight chosen for the rival's profit in the agent's performance evaluation and the correlation coefficient have the same sign. Then, given a positive (negative) correlation coefficient, an increase of the incentive weight $\mu_i^\dagger$ results in a decrease (increase) of the incentive rate $\nu_i^\dagger$. Otherwise, ambiguous relations result. To summarize, increasing the extent of RPE may yield stronger or weaker effort incentives.

Proposition 4 outlines the influence of the industry's competitiveness on the agents' effort incentives.

Proposition 4: Consider two firms with correlated firm profits. Then, under imperfect competition, the firms choose lower effort incentives as compared to two monopolist firms for $\mu_i^m \neq \mu_i^e$, and they choose equal effort incentives for $\mu_i^m = \mu_i^e$, $i = 1, 2$.

To prove Proposition 4, note that firm i is a monopolist if $\gamma_i = 0$. Then, agent ℓ's product market choice does not influence firm i's expected payoff, and principal i chooses μ_i to maximize the expected net payoff from the agent's effort choice, yielding (12b). With (11b) it is straightforward to show that effort incentives are maximized if $\mu_i = \mu_i^e$. Hence, effort incentives are largest for a monopolist firm.

The intuition for Proposition 4 is that in competitive industries, the principal's choice of the incentive weight for the rival's profit in the agent's performance evaluation trades off the benefit of a reduced systematic risk and the benefit of proper product market decisions. Given a monopolist firm, product market competition does not exist, and the incentive weight can be tailored to optimize the risk imposed on the agent.

3 Comparative Statics

3.1 Relative Performance Evaluation with Identical Firms

Subsequently, we consider the impact of several parameters on the relevance of RPE. Because of the complexity of the first order conditions, the subsequent analysis intensely uses numerical examples[22] plus the closed form solutions for some special cases. To illustrate the principals' basic trade-off between effort incentives, risk premium, and product market incentives, we first analyze the optimal extent of RPE in a setting with identical firms. Due to the symmetry of this setting, we restrict our analysis to symmetric solutions. Therefore, we omit the indices to ease the notation. Depending on the parameter values, multiple symmetric Nash equilibria may occur.[23] We assume that in these cases both principals select the equilibrium with the highest net payoff.

3.1.1 Trade-off between Effort Incentives, Risk-premium, and Product Market Incentives

With identical firms, following (12b) and (12d), the segregated choices for each principal of the incentive weight for optimal effort incentives and optimal product market incentives are

$$\mu^e = -\rho, \quad \text{and} \tag{16a}$$

$$\mu^m = -\frac{\gamma}{2\beta + \gamma}. \tag{16b}$$

[22] Due to the lack of generality inherent in numerical examples, our subsequent analysis (i) yields proofs for the existence of several highlighted characteristics of the solutions and (ii) illustrates our findings. We verified the optimal contract choices to satisfy the second order conditions by a change-of-sign test.

[23] We find multiple stable symmetric solutions in a setting comparable to Fumas (1992). Thus, our numerical results contradict Fumas (1992), Proposition 1(f), which states that for $\rho = 1$ the equilibrium is unique in general.

The optimal choice $\mu^\dagger$ balances the effects of effort incentives and product market incentives on the principal's aggregate net profit. Following Proposition 3, the segregated solutions μ^e and μ^m define boundaries of the set of optimal choices $\mu^\dagger$.

Figure 2 illustrates for a specific example the trade off between effort incentives and product market incentives. Here, $\alpha = 5$, $\beta = 2$, $\gamma = 1$, $b = 1$, $c = 1$, $r = 1$, and $\sigma = 1$.[24]

———— Insert Figure 2 here ————

According to Figure 2, $\mu^\dagger$ lies within the interval defined by μ^e and μ^m, and decreases with ρ. The intuition behind this result is that the principal's loss from setting $\mu^\dagger$ unequal to the solution of the segregated profits, i.e., $\mu^\dagger \neq \mu^j$, $j = e, m$ is a monotonically increasing non-linear function of the absolute difference between $\mu^\dagger$ and μ^j. Following (16a) and (16b), while ρ does not affect μ^m, μ^e decreases with ρ. Moreover, from Proposition 3 we know that $\mu^\dagger$ decreases (increases) if μ^e decreases (increases). Thus, $\mu^\dagger$ decreases with increasing ρ.

Result 1: With identical firms, the incentive weight for the rival's profit in the agent's performance evaluation decreases with the correlation of firm profits.

Fumas (1992), considering perfectly positively correlated firm's profits, concludes that "strategic competition and risk sharing considerations arrive at the same conclusion"[25] with respect to the general use of RPE, i.e., $\text{sign}\,(\mu^m) = \text{sign}\,(\mu^e)$. Figure 2, however, illustrates that this is not true if the correlation of firm profits is sufficiently negative. While $\mu^m \leq 0$ if $\gamma \geq 0$, $\mu^e > 0$ if $\rho < 0$. Hence, the sign of the boundaries differs if firm profits are negatively correlated.

Finally, given identical firms and a symmetric equilibrium, using (7a) in (10c), firm i's net payoff from product market competition is

$$\Pi_i^m(\mu) = \frac{(\alpha - c)(\beta + \gamma\mu)}{(2\beta + \gamma + \gamma\mu)^2}, \quad i = 1, 2\,.$$

With substitute products, i.e., $\gamma > 0$, Π_i^m is maximized for $\mu = 1$. Then, each principal motivates his agent to maximize joint product market profit, i.e., $\Pi^m = \Pi_1^m + \Pi_2^m$. However,

[24]Note, that the parameters meet the conditions we imposed in Sections 2.1 and 2.2.

[25]Fumas (1992), p. 483.

following Lemma 1 (b), $\mu = 1$ is not an equilibrium of the non-cooperative game. Moreover, $\mu^m < 0$ indicates that the principals are caught in a prisoner's dilemma, i.e., they increase their agent's aggressiveness in product market competition, although a softening would be mutually beneficial. Specifically, renouncing from the use of RPE, i.e., setting $\mu^m = 0$, would increase the expected net payoff Π^m.

Now, Figure 2 shows that each principal chooses $\mu^\dagger > 0$ if ρ is sufficiently negative, i.e., they both reduce their agent's aggressiveness in the product market competition. The key to this result is that the optimal $\mu^\dagger$ balances the effect of RPE on the principal's payoff from the agent's effort choice and from product market competition, and that the former payoff dominates if the principal can motivate the agent to supply a high effort level, i.e., if the correlation is sufficiently large. Then, a sufficiently positive correlation, i.e., $\rho > |\mu^m|$, results in an even more detrimental increase of the agent's aggressiveness. On the other hand, for $\rho < |\mu^m|$, the use of RPE to filter systematic risk results in a less aggressive behavior. Therefore, because of the use of RPE to filter systematic risk, the principals overcome the prisoner's dilemma and reduce their agents' aggressiveness in the market. Thus, ultimately, RPE results in higher expected net payoff to the principal.

3.1.2 Effort- versus Product Market-Incentives and Systematic Risk

Next, we consider the impact of systematic risk on RPE. With identically distributed noise and incentive weight μ, the variance of each agent's aggregate performance measure is

$$\mathrm{Var}[x_i + \mu x_\ell] = (1 + \mu^2 + 2\mu\rho)\sigma^2 , \qquad i, \ell = 1, 2, i \neq \ell,$$

i.e., with RPE the principal reduces the noise by the amount of $(\mu^2+2\mu\rho)\sigma^2$. Since the precision of each agent's aggregate performance measure decreases in σ^2, we interpret σ^2 as a measure indicating the amount of systematic risk imposed on each agent. Obviously, for $\sigma^2 = 0$, no systematic risk is imposed on the agents. Then, μ is chosen such as to maximize the net payoff from product market competition, i.e.,

$$\mu^\dagger \Big|_{\sigma^2=0} = \mu^m = -\frac{\gamma}{2\beta + \gamma} .$$

Figure 3 illustrates the impact of systematic risk σ on the weight for the rival's profit in the agent's performance evaluation for varying values of the correlation coefficient. Here,

$\alpha = 5$, $\beta = 2$, $\gamma = 1$, thus yielding the market size $s = 2\alpha/(\beta + \gamma) = 10/3$. Moreover, $b = 1$, $c = 1$, $r = 1$, and ρ varies in steps of 0.5. Following Figure 3, depending on the correlation coefficient ρ, fundamentally different comparative static results follow. For example, given a (positive or negative) unit correlation coefficient, $\mu^{\dagger}$ approaches unity with the opposite sign of the correlation coefficient for an increasing σ. With $\rho \neq \pm 1$, however, for an increasing σ, the optimal incentive weight approaches $\mu^{m} = -0.2$.

———— Insert Figure 3 here ————

The key to this result is the principal's ability to filter systematic risk, and the relative size of the payoffs from the agent's effort choice and from product market competition. First, assume that firm profits are perfectly correlated. Then, with $\mu = -\rho$, the principal completely filters incentive risk from the agent's compensation, and, following Corollary 2, the principal achieves maximum effort incentives. On the other hand, with the equilibrium choice for optimizing Π^{m}, i.e., for $\mu = -\gamma/(2\beta + \gamma)$, the principal imposes incentive risk on the agent, such that the agent's effort incentives decrease with increasing σ^2. Whereas for a low variance the benefits from product market competition may outweigh the losses due to lower effort incentives, the second effect exceeds the first for a relatively high variance. Thus, given perfectly correlated firm profits, a sufficient productivity of the agent's effort relative to the payoffs from the product market competition, and a noisy performance measure, the principal sets maximum effort incentives by removing any incentive risk from the agent's compensation. That is, $\mu^{\dagger}$ approaches unity with an increasing σ, i.e., with $|\rho| = 1$, we have $\mu^{\dagger} \to \mu^{e}$ and $\nu^{\dagger} \to 1$, if $\sigma \to \infty$.

Next, assume that firm profits are imperfectly correlated, i.e., $\rho \neq \pm 1$. Then, in general, RPE fails in eliminating systematic risk. While Π^{m} is independent of σ, $\Pi^{e}(\nu^{\dagger}, \mu^{e})$, with $\nu^{\dagger}$ following (11b), decreases with σ^2, i.e., providing effort incentives becomes more costly with increasing systematic risk. While reducing incentive risk may be beneficial for a relatively precise performance measure, for relatively unprecise performance measures the loss due to distorted product market incentives outweighs the benefit from a lower risk premium. Thus, given imperfectly correlated firm profits, an ambiguous relation between $\mu^{\dagger}$ and σ results, and for a relatively high variance, the principal chooses μ to optimize product market incentives. That is, with $\rho \neq \pm 1$, we have $\mu^{\dagger} \to \mu^{m}$, $\nu^{\dagger} \to 0$, and, therefore, $a^{\dagger} \to 0$, if $\sigma \to \infty$. While

$\nu^\dagger$ approaches zero and results in arbitrary small effort incentives, $\mu^\dagger$ continues to affect the product market decision, because a marginal incentive rate $\nu^\dagger$ is sufficient to influence the product market decision.

Now, consider a relatively large market size where the expected net payoff from product market competition exceeds the expected net payoff from the agent's effort choice. Given a sufficiently large s and perfectly correlated firm profits, multiple Nash equilibria arise for larger values of σ. Then, $\mu^\dagger$ approaches μ^m with an increasing σ. Therefore, given a relatively large market size, the optimal incentive weight $\mu^\dagger$ approaches μ^m with increasing systematic risk for $\rho \in [-1, 1]$. The key to this result is that for a sufficiently large market size, the payoff from product market competition dominates the principals' trade-off, such that even for perfectly correlated firm profits the principal chooses μ in order to maximize Π^m, i.e., $\lim_{\sigma \to \infty} \mu^\dagger = \mu^m$, and $\lim_{\sigma \to \infty} \nu^\dagger = 0$.

Result 2: With identical firms, the following relations exist between the optimal weight $\mu^\dagger$ for the rival's profit in the agent's performance evaluation and systematic risk σ:

(i) given perfectly correlated firm profits, and a relatively small market size, i.e., a sufficient productivity of the agent's effort, the weight for the rival's profit in the agent's performance evaluation monotonically approaches ± 1 with increasing systematic risk.

(ii) given imperfectly correlated firm profits, or a relatively large market size, the relation between the weight for the rival's profit in the agent's performance evaluation and the amount of systematic risk is ambiguous. The incentive weight approaches μ^m with increasing systematic risk.

Using the optimal incentive weights (11a) and (11b) in (10a) yields the total net payoff $\Pi^\dagger$ to the principal. Interestingly, given sufficiently negatively correlated firm profits, we find that $\Pi^\dagger$ may increase with σ. The key to this result is that increasing the systematic risk may help both principals to overcome the prisoner's dilemma. More specifically, given zero systematic risk, i.e., $\sigma = 0$, they choose $\mu^\dagger = \mu^m < 0$, which results in a lower expected net payoff as compared to $\mu = 0$. It is obvious from Figure 3, that, with negatively correlated firm profits, increasing σ may yield positive incentive weights $\mu^\dagger$. While the principals use the rival's profit to reduce the systematic risk imposed on the agent, Π^e decreases in σ due to the increase in the agent's risk premium. Since Π^m increases in μ, it is straightforward that the total net payoff $\Pi^\dagger$ increases with an increasing σ, if the increase in Π^m exceeds the loss in Π^e. This is the case, e.g., if the expected net payoff from product market competition exceed the expected net payoff from the agent's effort choice, i.e., if market size is sufficiently large.

3.1.3 Effort- versus Product Market-Incentives and the Intensity of Competition

Now, we analyze the impact of the competitiveness of the industry on the relevance of RPE. We interpret the degree of product differentiation, i.e., γ/β, as an indicator for the competitiveness of the industry, and alter the market's competitiveness by varying γ, while leaving β and s constant.[26] With $\alpha \in [s, 2s]$, $b = 1$, $c = 1$, $r = 1$, $\sigma = 1$, $\rho = 1$, $\beta = 2$, and $\gamma \in [0, 2]$, Figure 4 shows the influence of γ on the optimal incentive weight $\mu^\dagger$. Of course, the lowest competitiveness results for $\gamma = 0$, whereas competitiveness is strongest for $\gamma = \beta$, i.e., $\gamma/\beta = 1$.[27] While in the first case both firms are monopolists in their markets, in the latter case the products are homogeneous and the competitor has the same impact on prices as does the focal firm, yielding maximum competitiveness.

———— Insert Figure 4 here ————

Figure 4 illustrates that the relation between the weight for the rival's profit in the agent's performance evaluation and the industry's competitiveness is, in general, ambiguous.[28] First, note that with zero systematic risk, $\mu^\dagger = \mu^m$, $\partial\mu^\dagger/\partial\gamma < 0$, and that μ^m depends only on β and γ. Then, $\mu^\dagger = 0$ if $\gamma = 0$, i.e., RPE is not useful for motivating product market decisions if firms are a monopolists. Second, given zero competitiveness and non-zero systematic risk, i.e., $\gamma = 0$ and $\sigma \neq 0$, $\mu^\dagger = \mu^e = -\rho$, i.e., a monopolist chooses the incentive weight such

[26]With $s = 2\alpha/(\beta + \gamma)$, a variation in the degree of product differentiation affects the size s of the product market. Thus, holding β (γ) constant, increasing γ (β) lowers the market size and, consequently, the net profit from the product market competition, and vice versa. Varying the net profit from product market competition, however, alters the relation between the net payoffs from product market competition and from the agent's effort choice. Hence, to avoid this additional market size effect, we hold s constant by adjusting α. Note that our qualitative results hold true even if we did not adjust α.

[27]Note that for $\gamma = 0$ the quantity choice is independent of μ.

[28]Furthermore, with $\rho = 1$, Figure 4 captures the setting considered by Aggarwal/Samwick (1999). Figure 4 illustrates that their statement of a monotonic relation between the industry's competitiveness and the optimal weight of the rival firm's profit only holds true for a relatively small market, whereas, for a relatively large market, the relation is non-monotonic.

as to minimize systematic risk imposed on his agent. Now, given non-zero competitiveness and non-zero systematic risk, from Proposition 3 we have $\mu^\dagger \in (\mu^e, \mu^m)$ for $\gamma \in (0, \beta]$. Then Figure 4 shows, that $\exists \gamma \in (0, \beta]$ with $\partial\mu^\dagger/\partial\gamma > 0$ if ρ is sufficiently positive, and $\exists \gamma \in (0, \beta]$ with $\partial\mu^\dagger/\partial\gamma < 0$ if ρ is sufficiently low.

Moreover, Figure 4 indicates that the relation between $\mu^\dagger$ and γ depends on the market size. For example, with $\rho = 1$, $\exists \gamma \in (0, \beta]$ with $\partial\mu^\dagger/\partial\gamma < 0$. That is, while for $(\rho = 1, s = 3)$, $\mu^\dagger$ monotonically increases with γ, with $(\rho = 1, s = 10)$ the relation between $\mu^\dagger$ and γ is ambiguous. The key to this result is the relative size of the payoffs from product market competition and from the agent's effort choice. Given a relatively large market size, the first payoffs dominate, and for $\gamma \neq 0$ the principal is more interested in choosing μ such as to optimize product market competition. Hence, $\mu^\dagger(s) \geq \mu^\dagger(s')$ for all $\gamma \in (0, \beta]$ if $s \geq s'$. Since $\partial\mu^m/\partial\gamma \leq 0$, it is straightforward that $\exists \gamma \in (0, \beta]$ such that $\partial\mu^\dagger/\partial\gamma \leq 0$ if s is sufficiently large.

Result 3: With identical firms and positively correlated firm profits, the weight $\mu^\dagger$ for the rival's profit in the agent's performance evaluation is negative, whereas with negatively correlated firm profits the sign of the weight $\mu^\dagger$ is ambiguous. Moreover,

(i) given a relatively low positive or a negative correlation of firm profits, the incentive weight $\mu^\dagger$ decreases with the industry's competitiveness.

(ii) given a relatively large positive correlation of firm profits plus a relatively low market size, the incentive weight $\mu^\dagger$ increases with the industry's competitiveness.

(iii) given a relatively large positive correlation of firm profits plus a relatively large market size, the relation between the incentive weight $\mu^\dagger$ and the industry's competitiveness is ambiguous.

3.2 Relative Performance Evaluation with Heterogeneous Firms

Subsequently, we consider the use of RPE for heterogeneous firms. To simplify the comparison with the previous results, we assume that firms differ with respect to the precision of firm profits. Note that with heterogeneous firms, the equilibrium selection in case of multiple equilibria becomes more difficult. Of course, in general, only Pareto inefficient equilibria can be excluded. To simplify the analysis, we focus on numerical examples with unique feasible equilibria.

3.2.1 Trade-off between Effort Incentives, Risk-premium, and Product Market Incentives

First, with heterogeneous firms, consider the impact of the correlation coefficient on the weight for the rival's profit in the agent's performance evaluation. We continue to use the setting from Section 3.1, with parameter values $\alpha_1 = \alpha_2 = 15$, $\beta_1 = \beta_2 = 2$, $\gamma_1 = \gamma_2 = 1$, $b_1 = b_2 = 1$, $c_1 = c_2 = 1$, and $r_1 = r_2 = 1$. Additionally, we set $\sigma_1 = 2$ and $\sigma_2 = 1$, i.e., the performance measure of firm 1 is less precise than the measure of firm 2.

Figure 5 illustrates the optimal incentive weights $\mu_i^\dagger$, $i = 1, 2$, as well as the optimal weights for the segregated profits, i.e., μ_i^e and μ_i^m, for varying values of the correlation coefficient. Obviously, while the optimal weight decreases for the agent $i = 1$ with the less precise performance measure, the optimal weight for the agent $i = 2$ with more precise profits increases. Further, Figure 5 illustrates that with heterogeneous firms, the optimal weights μ_i^j, $i = 1, 2$, $j = e, m$ for the segregated profits no longer mark boundaries for the optimal weights $\mu_i^\dagger$.

———— Insert Figure 5 here ————

The key to this result is that, with different performance measure precisions, varying the correlation coefficient has a significantly different impact on the optimal effort incentives for the two firms. Moreover, the difference spill overs to the product market incentives. Principal 1 with a less precise performance measure needs to put more weight on the rival's profit to filter systematic risk from the agent's compensation as compared to principal 2 with a more precise measure. Thus, given a negative (positive) correlation coefficient, principal 1 softens (increases) his agent's aggressiveness in the product market. Then, however, it is beneficial for principal 2 to make contracting choices that are opposed to the choices of principal 1. More specifically, to gain market share, principal 2 increases his agent's aggressiveness if principal 1 softens his agent's aggressiveness, and principal 2 avoids a destructive competition by softening his agent's aggressiveness if principal 1 increases his agent's aggressiveness. As a consequence, for the example considered, principal 2 increases the weight for the rival's firm profit in his agent's performance evaluation if the correlation coefficient increases. To summarize, with heterogeneous firm risk, the relation between the incentive weight $\mu^\dagger$ and the correlation coefficient is ambiguous.

Result 4: With heterogeneous firm risk, the weight for the rival's profit in the agent's performance evaluation decreases with an increasing correlation of firm profits if the firm profit is relatively noisy, while the relation is ambiguous for firms with relatively precise firm profits.

3.2.2 Effort- versus Product Market-Incentives and Idiosyncratic Risk

Finally, we consider the impact of firm specific risk on RPE. Assume that the noise inherent in the profit is due to a common shock and an idiosyncratic shock, i.e., $\varepsilon_i = \varepsilon_m + \varepsilon_{fi}$, with the market-wide event $\varepsilon_m \sim \mathrm{N}(0, \sigma_m^2)$, the firm-specific events $\varepsilon_{fi} \sim \mathrm{N}(0, \sigma_{fi}^2)$, and $\mathrm{Cov}[\varepsilon_{f1}, \varepsilon_{f2}] = \mathrm{Cov}[\varepsilon_m, \varepsilon_{fi}] = 0$, $i = 1, 2$. Then, $\mathrm{Var}[\varepsilon_i] = \sigma_i^2 = \sigma_m^2 + \sigma_{fi}^2$, $\mathrm{Cov}[\varepsilon_1, \varepsilon_2] = \sigma_m^2$, and $\rho = \sigma_m^2/(\sigma_1\sigma_2)$. Obviously, the correlation coefficient ρ is non-negative, approaches unity for an increasing market risk, i.e., $\lim_{\sigma_m^2 \to \infty} = 1$, and approaches zero for an increasing firm-specific risk, i.e., $\lim_{\sigma_{fi}^2 \to \infty} = 1$, $i = 1, 2$.

It is straightforward that the optimal incentive weight μ_i^e, $i = 1, 2$, regarding agent i's effort incentives depends exclusively on the rival's firm-specific risk and the market risk, and is independent of own firm specific risk σ_{fi}:

$$\mu_i^e = -\frac{\sigma_m^2}{\sigma_m^2 + \sigma_{f\ell}^2}, \qquad i, \ell = 1, 2, \text{ and } i \neq \ell.$$

Moreover, $\lim_{\sigma_m^2 \to \infty} \mu_i^e = -1$, and $\lim_{\sigma_{f\ell}^2 \to \infty} \mu_i^e = 0$, $i, \ell = 1, 2$, and $i \neq \ell$. That is, while the use of RPE does not depend on own firm-specific risk, the principal more intensely uses RPE with increasing systematic risk, and he reduces the extent of RPE with an increasing rival firm-specific risk.

Figure 6 illustrates the optimal incentive weights $\mu_i^\dagger$, $i = 1, 2$ for varying degrees of firm-specific risk for firm 1. We continue to use the example from the previous section, but consider a relatively small market size, i.e., $\alpha_1 = \alpha_2 = 5$ and thus $s = 10/3$. Moreover, $\sigma_m = 1$, and

$\sigma_{f2} = 1$. Firm $i = 1$ specific risk σ_{f1} varies from 0 to 6, and the correlation coefficient ρ follows endogenously according to $\rho = \sigma_m^2/(\sigma_1\sigma_2)$.

———— Insert Figure 6 here ————

With increasing σ_{f1}, the optimal weight $\mu_1^\dagger$ first increases and then decreases (slightly), while $\mu_2^\dagger$ increases for $\sigma_{f1} \in [0, 6]$.[29] Obviously, the impact of firm-specific risk σ_{f1} on $\mu_2^\dagger$ corresponds to the impact of σ_{f1} on μ_2^e. Unlike the optimal incentive weight μ_1^e regarding the segregated profit Π_1^e for agent 1's effort choice, $\mu_1^\dagger$ varies with σ_{f1}, i.e., own firm-specific risk influences the extent of RPE. Specifically, the relation between $\mu_1^\dagger$ and σ_{f1} is ambiguous.

To grasp the intuition for Figure 6, note that with an increasing firm-specific risk the correlation of firm profits is decreasing. As a consequence, principal 2 increases $\mu_2^\dagger$, since he is less able to remove incentive risk from his agent's compensation. The impact of σ_{f1} on $\mu_1^\dagger$ is more subtle. Equivalent to principal 2, with a decreasing correlation of firm profits, the ability to filter systematic risk decreases. In addition, increasing firm-specific risk reduces the precision of firm 1 profits, thus reducing the relevance of the payoffs from agent effort as compared to the payoffs from product market competition. As a consequence, principal 1 emphasizes the payoffs from product market competition if the firm-specific is sufficiently large. While emphasizing product market competition results in a more aggressive behavior for firm 1 agent, principal 2 reacts by softening his agent's behavior. Therefore, given a sufficiently large firm-specific risk, the optimal weight for the rival's profit in agent 1's performance evaluation , i.e., $\mu_1^\dagger$, increases with σ_{f1}.

Result 5: With heterogeneous firm risk and positively correlated firm profits, the weight $\mu_i^\dagger$ for rival ℓ's profit in agent i's performance evaluation is negative, $i, \ell = 1, 2$, $\ell \neq i$. Moreover,

(i) the incentive weight $\mu_\ell^\dagger$ decreases with rival i's firm specific risk.

(ii) the incentive weight $\mu_i^\dagger$ varies with own firm specific risk.

(iii) given a relatively low firm specific risk, the incentive weight $\mu_i^\dagger$ increases with own firm specific risk.

[29] Note, that for $\sigma_{f1} = 1$, the firms are identical, such that the incentive weights are identical.

(iv) given a relatively large firm specific risk, the incentive weight $\mu_i^\dagger$ decreases with own firm specific risk.

4 Empirical Implications and Concluding Remarks

In this paper, we examine incentive contracts for a setting with two principal/agent-relations. Due to product market interdependencies, contract externalities arise that influence the contracting game played by the principals. As a result of these frictions, optimal managerial incentives are, in general, linked across firms.

For identical firms, we show that the solutions that maximize the segregated payoff from the agent's effort and from the product market competition, respectively, define boundaries to the solutions of the integrated problem. Moreover, our analysis indicates that the sign of the optimal weight on the rival firm's profit in the agent's performance evaluation may differ from the opposite sign of the correlation coefficient. Of course, the ambiguous relation of both signs complicates empirical tests for RPE.

Our numerical comparative static analysis indicates that, given identical firms, the weight on the rival firm's profit in the agent's performance evaluation decreases with the correlation of the firms' profits. With heterogeneous firms, however, this relation holds true only for firms with a relatively low precision of firm profit. Then, a positive relation may result for firms with a relatively high precision. Thus, empirically testing for RPE without discriminating for the precision of the performance measure introduces a bias against detecting the use of RPE. Regarding the criteria for discrimination, however, our results indicate that the relation between the extent of RPE, systematic risk, and firm specific risk, is ambiguous.

Finally, we find that, in general, firms in more competitive industries may use more as well as less RPE as compared to firms in less competitive industries if firms compete in quantities. Discriminating with respect to the correlation between firm profit and a market portfolio, we expect that for firms with a relatively small correlation the extent of RPE increases with the industry's competitiveness, whereas it decreases for firms with a relatively large correlation.

Moreover, our results indicate that the heterogeneity of firms substantially influences the optimal weight for the rival firm's profit in the agent's compensation scheme. Especially, we find that heterogeneous firms in the same industry may place a fundamentally different weight on RPE. More specifically, due to the contract externalities, firm-specific risk influence the incentive weight on the rival's profit in the agent's performance evaluation. While the rival's use of RPE decreases in the amount of firm-specific risk, the opposite relation may result for the firm under study. Thus, we provide a theoretical foundation for Albuquerque (2005), who finds strong evidence for RPE using peer groups of similar sized firms within specific industries. Finally, our analysis suggests that there are fewer effort incentives in an oligopolistic firm as compared to a monopolist firm, since optimal incentive schemes incorporate product market effects yielding equilibria characterized by inefficient effort incentives.

To summarize, our result supports more differentiated comparative statics results that may improve the discrimination of data sets. Then, we expect stronger empirical evidence regarding the implicit extent of RPE.

Appendix – Proof of Proposition 3

Given identical firms and a feasible set of parameters, the differentials of the segregated profits yield the following properties:

$$\begin{aligned}
&\frac{\partial}{\partial \mu_i} \Pi_i^e(\nu_i^\dagger(\mu_i), \mu_i)\Big|_{\mu_i \equiv \mu} > 0, \qquad \forall \mu < \mu^e, \\
&\frac{\partial}{\partial \mu_i} \Pi_i^e(\nu_i^\dagger(\mu_i), \mu_i)\Big|_{\mu_i \equiv \mu} < 0, \qquad \forall \mu > \mu^e, \\
&\frac{\partial}{\partial \mu_i} \Pi_i^m(\mu_i, \hat{\mu}_\ell)\Big|_{\mu_i = \mu_\ell = \hat{\mu}_\ell \equiv \mu} > 0, \qquad \forall \mu < \mu^m, \\
&\frac{\partial}{\partial \mu_i} \Pi_i^m(\mu_i, \hat{\mu}_\ell)\Big|_{\mu_i = \mu_\ell = \hat{\mu}_\ell \equiv \mu} < 0, \qquad \forall \mu > \mu^m, i, \ell = 1, 2, \text{ and } i \neq \ell.
\end{aligned}$$

Assuming a symmetric solution, the first order condition of the integrated problem is

$$\frac{\partial}{\partial \mu_i}\Big[\Pi_i^e(\nu_i^\dagger(\mu_i), \mu_i) + \Pi_i^m(\mu_i, \hat{\mu}_\ell)\Big]\Big|_{\mu_i = \mu_\ell = \hat{\mu}_\ell \equiv \mu} = 0\,.$$

(i) First consider $\mu^e < \mu^m$. With μ^e and μ^m as the unique solutions to the segregated problems, the first order conditions of the integrated problem require

$$\text{sign}\left(\frac{\partial}{\partial \mu_i} \Pi_i^e(\nu_i^\dagger(\mu_i), \mu_i)\right) \neq \text{sign}\left(\frac{\partial}{\partial \mu_i} \Pi_i^m(\mu_i, \hat{\mu}_\ell)\right),$$

which is only true for $\mu^e < \mu_i < \mu^m$.

(ii) The proof for $\mu^e > \mu^m$ is analogous to (i).

(iii) Finally, consider $\mu^e = \mu^m$. Since the signs of the differentials of the segregated profits are identical in case of $\mu < \mu^e = \mu^m$ and $\mu > \mu^e = \mu^m$, $\mu^\dagger = \mu^e = \mu^m$ is the unique solution to the integrated problem.

Note that for heterogeneous firms, the relevant signs of the differentials regarding $\Pi_i^m(\mu_i, \hat{\mu}_\ell)$ may differ. Thus, the segregated solutions do not define boundaries for the integrated solutions. $\square$

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Figure 1: Impact of the Incentive Contracts on the Agents' Reaction Functions

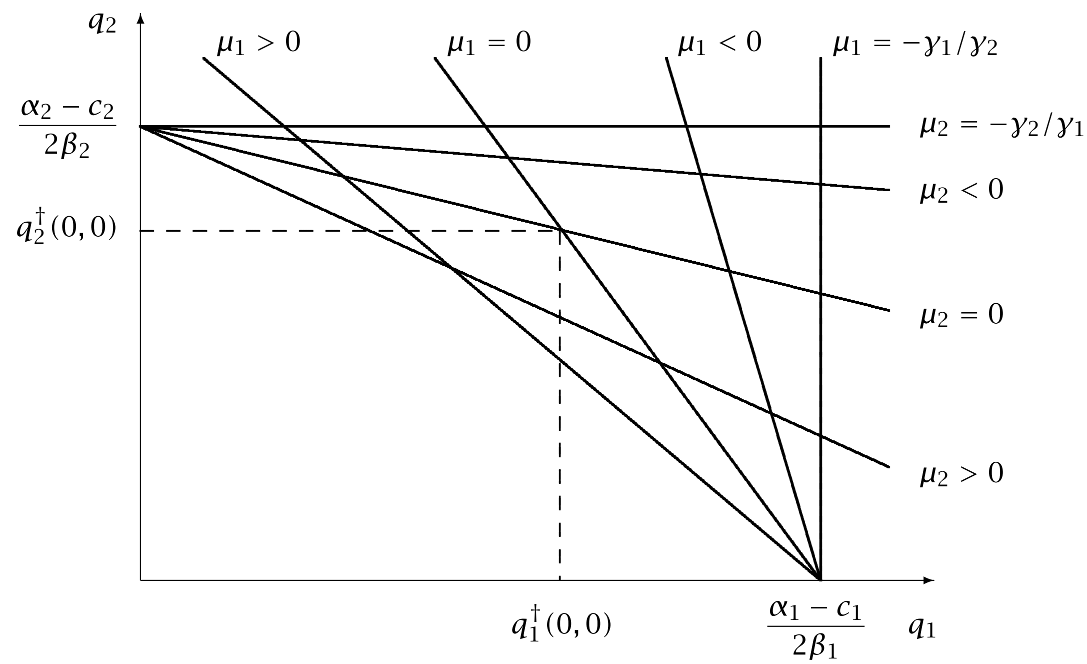

Figure 2: Optimal Relative Performance Evaluation and the Correlation of Firms' Profit for Identical Firms

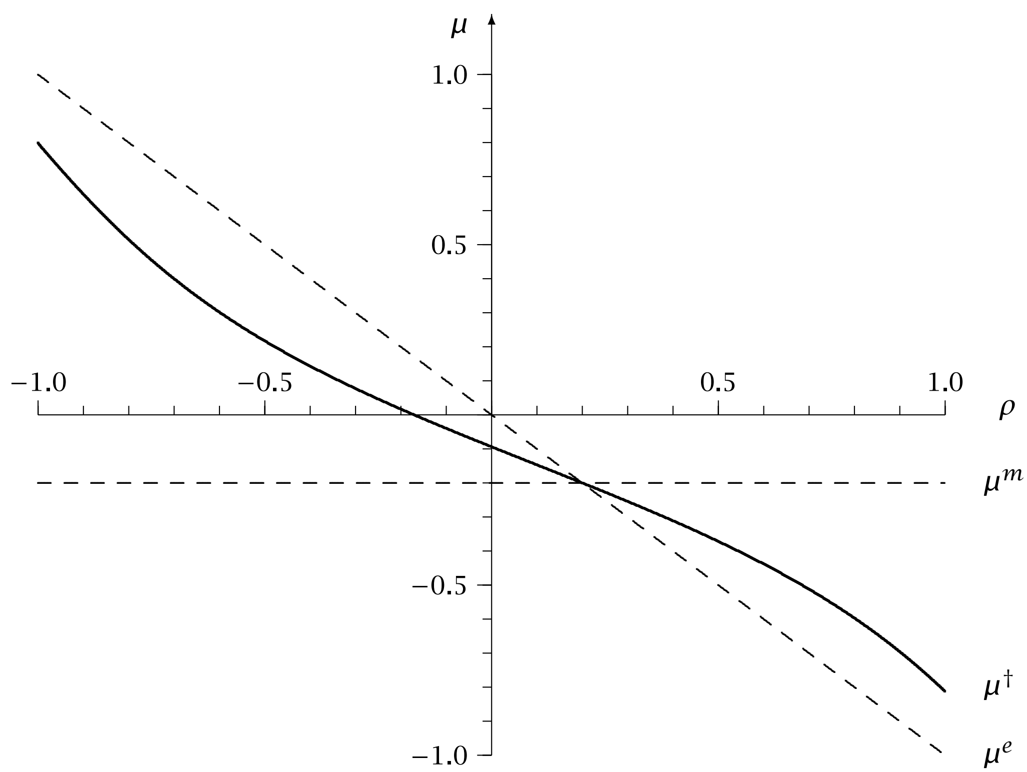

Figure 3: Optimal Relative Performance Evaluation and Systematic Risk

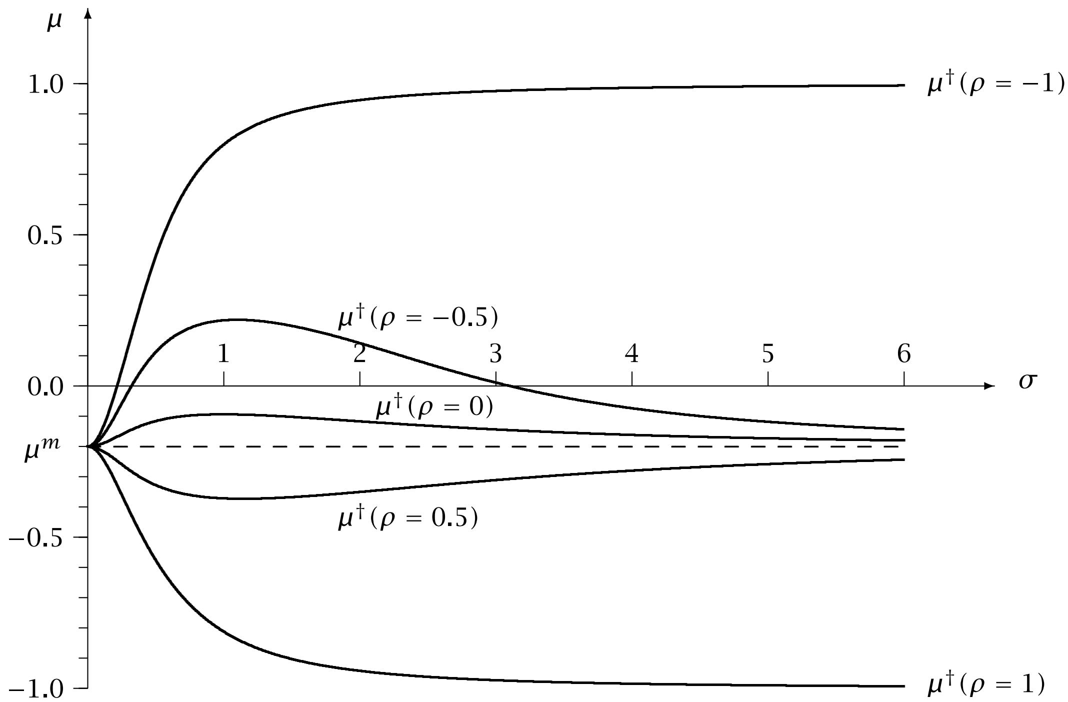

Figure 4: Optimal Relative Performance Evaluation and the Intensity of Competitiveness

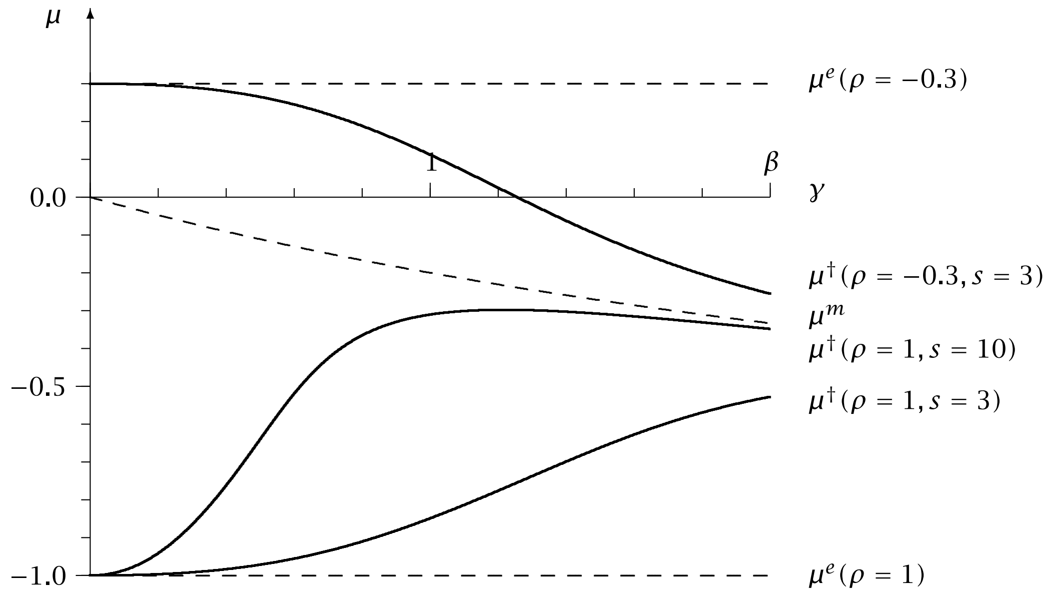

Figure 5: Optimal Relative Performance Evaluation and the Correlation of Firms' Profit for Heterogeneous Firms

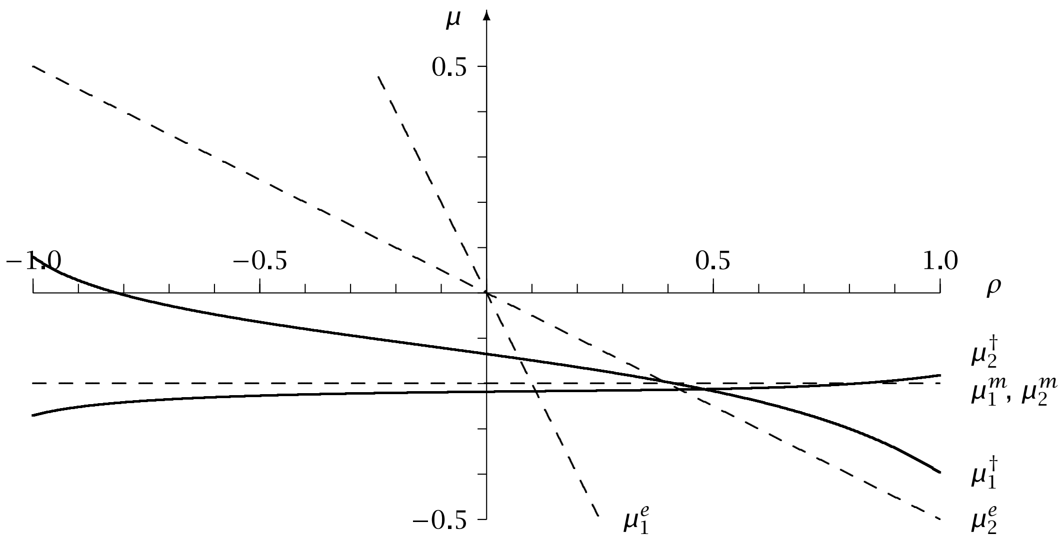

Figure 6: Optimal Relative Performance Evaluation and Idiosyncratic Firm Risk