Incentives and spillovers in R&D activities: an agency-theoretic analysis of industry-university relations*

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Abstract

In this paper, I study industry-university relations in a principal-agent framework. Following the existing literature, these relations are interpreted in two ways: (1) as occurring through spillovers of knowledge among different groups of researchers, working for different institutional settings; or (2) as more formal interactions, through the possibility, for a scientist, to directly respond to incentives defined by the different communities she may belong to. I formalize these two configurations in a unified framework. I account for: (1) the inherent difficulty in measuring the impact of scientific activities; and (2) the multiplicity of activities that scientists perform. I combine multi-task agency models with distorted performance measures and common agency models. My model identifies several types of incongruities between an agent's actions and the desired outcomes. These incongruities derive also from the strategic interaction among the principals. I also identify some potentially distortionary behavioral effects of the presence of spillovers.

Keywords: Economics of Science; Agency Theory; Industry-University Relations; Science Policy; R&D Management.

1 Introduction

The modern literature on the Economics of Science has made important progress in the last 30 years. The original insights on the public nature

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of knowledge, by Nelson (1959) and Arrow (1962), have represented the basis of these developments. Two broad streams of research can be identified as having extended those pathbreaking works.

Some scholars have stressed the complexity and uncertainty of the production of scientific knowledge and of its transmission and absorption. Knowledge is assumed to be dispersed among heterogeneous actors, and communication is not immediate. The 'linear model' [basic research–>applied research (–>development)] is rejected. Uncertainty, serendipity, feedback from users, heterogeneous capabilities, etc. are taken as important (Von Hippel (1988), Rosenberg (1990, 1994), Nelson (1990, 2003), Nightingale (2000), Salter and Martin (2001)). Different capabilities and different institutional actors produce beneficial diversity and potential spillovers of knowledge.

A second stream of research, called the 'New Economics of Science' (NES hereafter), interprets Science as, first of all, an institution. This institution has peculiar rules and a reward system, priority-based, that stimulates openness and disclosure. Other institutions, driven by different objectives, also perform research. The decision to perform different types of research is endogenous and depends on the incentive systems. This approach draws from sociological analyses of Science (Merton (1957), Glaser (1964), Blume (1974), Long and McGinnis (1981)). The NES also draws from modern economic theory, especially the Economics of information, contracts and organizations.

These two views, taken together, depict scientific and innovative activities as complex processes, resulting from the presence of several types of actors (firms, universities, etc.), their coordination, and the presence of institutional incentives that guide the actions of individuals, groups and organizations. They have offered important contributions to dealing with issues of science policy as well as of the organization of research activities in business firms.

An issue of recent interest has concerned the interaction between academia and the business sector. Traditionally, industry-university relations have been seen as occurring through informal channels, such as knowledge spillovers. More recently, much attention has been devoted to more formal and explicit forms of relations. The perception of a decline in US competitiveness in the 1980s has induced a series of reforms meant to increase the contribution of universities and public research centers to the growth of the economy. Legislative interventions, like the 1980 Bayh-Dole Act, have de facto promoted much stronger university-industry relations. Policy makers in Europe have looked at these developments with great interest .

The scholarly debate has been intense. For approaches that have deepened the analysis of the nature of knowledge, an excessive degree of industry-university relationships may present a dilemma. On the one hand, the transmission of knowledge is made easier, since spillovers between different organizations will be imperfect in the absence of direct interaction. On the other hand, some benefits from diversity may get lost if relationships are too strong. However, these points raise some questions. For example, it is not clear why interaction should automatically reduce diversity. Also, the effects of the presence of spillovers on incentives to perform research are not frequently explored. The institutional spirit of the New Economics of Science may offer insights. For example, an issue of analysis in the NES is the ability of universities to continue promoting basic research, if they are allowed to interact (either compete or cooperate) with the business sector through patenting and licensing activities. Similarly, concerns are raised on the ability of business firms to commit to long-term, uncertain basic research, because of conflicting objectives. Despite the roots in the Economics of Contracts, few formal models of these issues are available. Much of the literature on industry-university relations has, indeed, developed at an informal or empirical level.

In this paper, I offer an agency-theoretic perspective on the relationships between different institutions in the performance of research. I employ some of the theoretical tools developed since the late 1980s (see Gibbons (2003) for a review). The multidimensionality of the effort of a scientist (the agent), and the difficulty to reward scientific activities, are seen as defining a multi-task principal-agent problem with distorted performance measures (Holmstrom and Milgrom (1991), Baker (2003), Datar et al. (2001), Feltham and Xie (1994)). I analyze, in this framework, the role of knowledge spillovers among different research agents, working for different organizations (principals). I show that even these informal interactions may have some important effects on incentives, strategic behavior and the informativeness of the performance measures. These implications have been rarely considered to date. I interpret more direct forms of interactions, like formal university-industry relationships, as the possibility, for a scientist, to have multiple affiliations or to directly respond to different types of institutional rules: a case of common agency (Bernheim and Whinston (1986), Dixit (1997), Dixit et al. (1997), Mezzetti (1997)). In this case, I show that the main trade off is between the reduction of duplication of effort, and the excessive free-riding behavior on the part of the principals.

The paper is organized as follows. In Section 2, I provide a brief summary of the insights of institutional approaches to Science that I see as particularly relevant for my study. I also review some of the existing literature on industry-university relations. In Section 3, I propose an agency-theoretic model of industry-university relations. A discussion and some numerical examples are also presented. Section 4 offers concluding remarks. Bibliographic references are in Section 5. Tables and figures are in Section 6. An appendix is provided in Section 7.

2 The institutional analysis of Science

2.1 Dasgupta and David (1994)

'Both the corporate scientists and their academic rivals are obsessed with winning, and they continually fret that the competition will publish a critical finding first' (D. Stipp, Wall Street Journal, Feb. 1994)

'In addition to ribbon, the tangible rewards for doing science include gold.' (Stephan and Levin 1992, p. 20).

I now present in a few points the main features of the institutional approach to the economic analysis of scientific research proposed by Dasgupta and David (1994, DD hereafter). This paper offers a rather comprehensive view of the New Economics of Science. Recalling the main points of this article will help to understand the development of my analysis.

1. If we focus our attention on the social arrangements that guide scientific activity, we encounter two major institutional models. One of them, called the 'Republic of Science' (Polanyi (1962)), has the maximal diffusion of knowledge as key objective. Its basic rules are the principle of priority in discovery as reward system, the disclosure of discoveries, and free access to them, typically through scientific publication or sharing of data, instrumentation, etc.[1] Universities and publicly funded research organizations are the natural, though not exclusive, places for such institutional form. The other institutional model is called the 'Realm of Technology', and the major objective is to obtain economic rents from scientific research. Privacy and non-disclosure will prevail in this environment. Industrial R&D is the typical locus for this organizational mode. The Republic of Science and the Realm of Technology are therefore meant for different, complementary functions, and both are potentially valuable for society.

2. The key distinction between open science and industrial R&D is therefore not in terms of the activities that are performed, e.g. 'science

[1] Another key feature of the Republic of Science is the evaluation based on peer review. David (1998) identifies two factors that explain the origin of this 'open science' system: (1) the Scientific Revolution; and (2) and the compensating mechanism defined by aristocratic patronage. Both epistemological and institutional factors are therefore highlighted.

vs. technology' or 'applied vs. basic research'. The choice of performing basic vs. applied research is endogenous, and depends on the incentive systems set up by the different organizational forms.

3. Evaluating scientific activity and the quality of discoveries is extremely difficult due to the multifaceted nature of the activities and the complexity of the knowledge base. The definition of incentives and the allocation of resources, therefore, take into account both the different objectives and the difficulties arising from such information asymmetries. In the Republic of Science, for example, the priority-based system is the response to the necessity of defining incentive schemes on observable performance, and to the difficulty of awarding prizes based on ranks[2]. This reward system also enhances public disclosure and stimulates new findings. These devices can be therefore seen as second-best choices.

What is strongly stressed, in the light of the previous points, is the necessity of maintaining both institutional settings and of keeping them relatively separated and differentiated. We can see this analysis as a concerned response to some perceived changes in the orientation of science policies in major Western countries (especially the US) since the 1980s.

While there is a strong claim in favor of institutional diversity as expressed by institutions having different objectives, the authors do not fully explore how interactions translate into incentive systems, even maintaining different institutional goals.

2.2 The related literature on industry-university relations

Several studies have recently focused on the process toward a 'privatization' of academic activities, for example the possibility for universities to license also discoveries emerging from publicly funded projects (as from the 1980 Bayh-Dole Act and further reforms in 1984) or the possibility of sharing the revenues of licenses between the university and the single inventor. The debate has mainly concerned the risk of excessive similarities between the institutional goals and the incentive systems of closed and open science, because of distortionary effects on behavior. However, potential complementarities between different kinds of activities have

[2] This reward system also enhances public disclosure and stimulates new findings. These devices can be therefore seen as second-best choices. Moreover, they generate some congruity between the interests of the scientific community and the societal interest more in general. For, from the point of view of the society, the value of 'arriving second', i.e. of discovering something that has already been discovered, is zero. Finally, the authors also discuss several potential distortions deriving from these systems. I will not refer to them here.

also been considered [3].

The majority of the studies, however, have taken the economic-theoretical issues of DD as a 'background', and have proposed verbal arguments and empirical evidence consistent with them. This might limit our ability to analyze the behavioral effects of different forms and degrees of interaction among different institutions.

Some very recent works have taken a step forward to formal analysis[4]. Lach and Schankermann (2003) make an explicit reference to organizational and contract theoretic tools. They define a multi-task setting to analyze how monetary incentives affect the choice of academic scientists to license their discoveries. However, the preferences of scientists for performing different activities are somewhat taken as given and not endogenized as response to different kinds of incentives. Jensen et al. (2003) model the process of faculty disclosure and university licensing through a Technology Transfer Office as an agency problem, where both the faculty and the TTOs are agents of the same principal, the University. Differently from the framework I will propose, the authors do not explicitly consider the multidimensionality of effort. Also, the multiplicity of affiliations is not analyzed directly.

Other two works are noteworthy in the study of the relations between different institutions in research activities. Stern (1999) models the choice of the first-long term job position of research scientists. He tests his model on a sample of biology post-docs, and finds that researchers are willing to accept a lower monetary compensation from their (profit oriented) employers if they are allowed to keep relations with the external scientific community. However, the interaction with the scientific community and its incentive system are taken as given and not modeled, or only partially endogenized. Cockburn et al. (1999) build a model of research activities based on the multi-task agency theory of Holmstrom and Milgrom (1991, 1994). They find that, in drug companies, incentive provisions to perform basic and applied research are complementary. Incentive for basic research are expressed as rewards

[3] See, among others, Lee (1996), Henderson et al. (1998), Powell and Owen-Smith (1998), Stephan et al.(2002), Nelson (2003), Goldfarb et al. (2003), Sampat et al. (2003), Ranga et al. (2003). The finding of Levin and Stephan (1991) on the presence of a 'life cycle' in the productivity of scientists, with a decline over time, is interpreted by the authors also as a warning about the progressive 'ageing' of university scientists. This ageing may be caused by the increasing similarity of academia with the business environment, and the comparative advantage of the latter in providing monetary incentives and to look more attractive to young talented scientists.

[4] I am referring, here, to contractual and organizational analyses. Formal modeling of related phenomena, for example on the creation of social networks, is also developing. See for example Cowan and Jonard (1999).

for a good standing in the scientific community. A limit, in this case, is that the interaction between different institutional settings is missing, since only one objective is expressed, i.e. economic profit maximization. Moreover, the major distinction seems to be in terms of types of activities and not in terms of different institutional goals.

I now turn to my model.

3 A model

I focus on the effects of different forms of interaction between different institutional settings. I take the coexistence of different objectives by different communities as granted, and analyze the impact on the incentives for the agents.

Here is a summary of the aspects I want to model:

- Scientific activities are performed in institutional settings having different objectives. Scientific effort is multidimensional.

- The evaluation of scientific effort in inherently problematic. First, the results are highly uncertain, and so is their value. Second, observing and evaluating what scientists really do is difficult and costly.

- The activity of a scientist may also influence the activity and the performance of other scientists, working for the same organization or for others, through knowledge spillovers.

The joint considerations of all these phenomena is novel in the economic analysis of research activities. A principal-agent perspective offers a potentially valuable framework for such a combination. The constructs I see as relevant are:

- Multi-task environment, multi-dimensional effort choice, distorted performance measures. Each of the objectives (and performance measures) I refer to is potentially affected by more than one kind of effort; the output is not verifiable (by a third party), while there are verifiable performance measures available; the marginal effects of the agent's effort on the contractible measure may not be perfectly aligned to the effect on the 'true' objective measure[5].

- Common agency: the formal interaction between the two communities can be seen, in agency theoretic terms, as a case in which several principals try to affect the behavior of the same agent (see Bernheim and Whinston (1986), Mezzetti (1997)); conversely, we may have different agents responding to different principals.

I consider two configurations: (i) the presence of two separate communities of scientists working for separate organizations with different

[5]This configuration differs from the Holmstrom-Milgrom treatment and is more akin to Feltham and Xie (1994), Datar et al. (2001), and Baker (2003).

goals, say 'Science' and 'Business'; (ii) a unique community of scientists affiliated with, and responding to both organizations[6]. The commercial use of university research 'simply' through knowledge spillovers will (loosely) correspond to case (i). More formal and explicit forms of interaction between business and academia can be seen, at their extreme, as represented by case (ii).

3.1 The general environment

Assume that there are two principals, say the scientific community and a business firm. Each community has an objective, and needs the services of an agent to pursue this goal. The two principals may each have one separated agent (or team, see footnote 6). Alternatively, the same agent can work for both communities. This latter configuration is called 'common agency' or 'interaction'. I call the former case 'exclusive dealing' or 'separation'.

The objective of the scientific community (or institution A) is the generation of knowledge. The knowledge production function can be expressed as follows:

$$K = k_1 e_1^A + k_2 e_2^A + \beta_1 e_1^B + \beta_2 e_2^B + \varepsilon_K \qquad (1)$$

where e_1^A and e_2^A represent the effort levels of the agent working for A (agent A), in two distinct activities; we can call them applied (e_1^A) and basic (e_2^A) research. k_1 and k_2 are parameters representing marginal productivities. In addition, when two agents (or teams) are present, and work for each of the two different institutions, they influence also the outcome of interest of the institution for whom they do not formally work. This is captured, in expression (1), by $\beta_1 e_1^B + \beta_2 e_2^B$, and I call this a spillover of knowledge. ε_K is an error term indicating stochastic shocks, as well as the unmodeled influence of other factors. The expected value of ε_K, as well as that of all the other error terms that follow, is normalized to zero.

The business sector (institution B) is interested in the production of economic rents, or profits, from research activities, which I model as:

$$P = p_1 e_1^B + p_2 e_2^B + \sigma_1 e_1^A + \sigma_2 e_2^A + \varepsilon_P \qquad (2)$$

where the explanation of the terms is just as for expression (1). We assume therefore that both kinds of activities may influence the production of knowledge and the generation of economic profits. In addition,

[6] I do not consider, here, the problems emerging from teamwork, like free riding etc. When I talk about a group of agents, I consider them as a unique decision maker.

we consider the role of spillovers, when different teams work for different institutions.

If only one team is present and works for both communities, then the spillover terms will not be present. The unique agent affects simultaneously both objectives. Expressions 1 and 2 reduce to:

$$K = k_1 e_1 + k_2 e_2 + \varepsilon_K \tag{3}$$

$$P = p_1 e_1 + p_2 e_2 + \varepsilon_P \tag{4}$$

It is not possible, however, to provide incentives based on outcomes K and P: they are too complex to be verified by a third party (see Baker (1992, 2003)). Two contractible performance measures are available: production of scientific articles and of patents. They are modeled as:

$$X = \phi_1 e_1^A + \phi_2 e_2^A + \delta_1 e_1^B + \delta_2 e_2^B + \varepsilon_x \tag{5}$$

for publications, and

$$Y = \gamma_1 e_1^B + \gamma_2 e_2^B + \eta_1 e_1^A + \eta_2 e_2^A + \varepsilon_y \tag{6}$$

for patents.

Similarly to what said just above, these expression reduce, in the case of common agency, to:

$$X = \phi_1 e_1 + \phi_2 e_2 + \varepsilon_x \tag{7}$$

$$Y = \gamma_1 e_1 + \gamma_2 e_2 + \varepsilon_y \tag{8}$$

The marginal impacts, as well as the unexplained components in the error terms, are allowed to differ from those of the 'true' objectives. For example, a researcher's effort may be very strongly affecting the generation of patentable innovations, but these innovations may be not so valuable in terms of overall profits for the firm[7].

Both performance measures are potentially relevant with respect to both objectives. They may add information to reward unobservable effort and to filter out some uncertainty. In what follows, I assume risk neutral agents so the issue of risk-filtering is not relevant. Regarding the addition of information, I restrict to cases where publications are the

[7] See, among others, Agrawal and Henderson (2002) for some considerations about the imperfect role of published and patented research in predicting the value of the produced knowledge and also of the knowledge used in the business sector. See also Griliches (1990).

only 'natural' performance measure for the production of knowledge in the academia, and the same holds for patents with respect to profits in the 'Realm of Technology'[8]. I am therefore considering a configuration where only one performance measure is available to each principal. I am aware that this is a limitation, but I believe that the model still gives some interesting insights[9].

Finally, notice that the spillovers on the performance measures may differ from those on the objective functions. In addition, the spillovers on the performance measures do not have any direct impact on welfare. As we will see shortly, they will have an informational and strategic role, which existing analyses (both formal and informal) have not considered explicitly.

The disutility of effort for each agent is a simple quadratic and separable function:

$$C = \frac{e_1^2}{2} + \frac{e_2^2}{2} \tag{9}$$

As for the wage schedule, I adopt a linear incentive scheme. I also exclude the presence of a fixed salary. Linear wage schemes produce fairly tractable models. The absence of a fixed salary serves to produce uniqueness of the solutions in the common agency case. This will be clear later[10]. The outside option is equal to zero for all parties.

3.1.1 The timing and the equilibrium concepts

The timing of the game is represented in figure 1. In the first stage (t=1), the principals simultaneously set their optimal piece rate. In the second

[8]Several studies have used publications as a proxy of knowledge production in academe and patents as a measure of research and innovative activities in firms. For a recent example, see Agrawal and Cockburn (2003).

[9]A situation I am apparently excluding is the patenting activity by universities. However, the common agency case can be interpreted as implying the decision by open science organizations to allow scientists participating to the work of the business sector and to give them all the royalties from such activities. I am also excluding 'philanthropic finalities' of business firms, which may set up private foundations that pursue the generation of new knowledge as an end in itself. However, we can think of these foundations as separate entities with respect to the 'parent' company, and therefore as an additional principal with a different set of objectives (I am therefore not assuming that the company, by setting a separate foundation, jointly maximizes the economic rents and the production of scientific knowledge). In a partially different perspective, my choice can be interpreted as an assumption of the inability of a given organization to commit to certain ultimate objectives, different from their 'natural' ones. See, for example, Acemoglu et al. (2003).

[10]See the Appendix. The choice of linear incentives schemes by the principals in such a setting, different from the one depicted in Holmstrom and Milgrom (1987), may not necessarily be optimal. Indeed I do not make any claim in this sense.

stage (t=2), the agent(s) chooses (choose) her level of effort, given the choice of the piece rates. The appropriate concept of equilibrium to be applied, here, is subgame perfect Nash equilibrium. I therefore solve the game by backward induction. In t=1 a simultaneous game, among principals, is taking place.

3.2 Exclusive dealing

Institution A defines the following incentive scheme for its agent (agent A)[11]:

$$W_A = \alpha_A^{sep} X \tag{10}$$

where α_A^{sep} is the piece rate and X is defined in expression (5). The risk neutral agent maximizes her expected payoff $E(W_A - C)$ with respect to e_1^A and e_2^A, and will choose:

$$e_1^A = \alpha_A^{sep} \phi_1 \tag{11}$$

$$e_2^A = \alpha_A^{sep} \phi_2 \tag{12}$$

Agent B, similarly, will choose

$$e_1^B = \alpha_B^{sep} \gamma_1 \tag{13}$$

$$e_2^B = \alpha_B^{sep} \gamma_2 \tag{14}$$

These choices define the Incentive Compatibility (IC) constraints that the principals consider. Principal A solves:

$$Max_{\alpha_A^{sep}} \{E(\Pi_A) = E(K - \alpha_A^{sep} X)\} \text{ subject to: (11) to (14)} \tag{15}$$

Institution B solves:

$$Max_{\alpha_B^{sep}} \{E(\Pi_B) = E(P - \alpha_B^{sep} Y)\} \text{ subject to: (11) to (14)} \tag{16}$$

Plug (1), (5) and (11) to (14) into (15); and (2), (6), and (11) to (14) into (16). Determine the (necessary and sufficient) first-order conditions of (15) with respect to α_A^{sep}, and of (16) with respect to α_B^{sep}.We get the reaction functions:

$$\alpha_A^{sep} = BR(\alpha_B^{sep}) = \frac{k\phi}{2|\phi|^2} - \frac{\delta\gamma}{2|\phi|^2}\alpha_B^{sep} \tag{17}$$

$$\alpha_B^{sep} = BR(\alpha_A^{sep}) = \frac{p\gamma}{2|\gamma|^2} - \frac{\phi\eta}{2|\gamma|^2}\alpha_A^{sep} \tag{18}$$

[11] I am implicitly assuming that any kind of income is in monetary terms or can be translated in monetary terms.

BR stands for 'best response'. I call $k = (k_1, k_2)$ and $|k| = \sqrt{k_1^2 + k_2^2}$ (norm of k or Euclidean distance from the origin) and the same notation is used for all the other two-dimensional vectors of coefficients.

Solving simultaneously (17) and (18) gives the Nash equilibrium piece rates:

$$\alpha_A^{sep} = \frac{|\gamma|(2|k||\phi|\cos\theta_{k\phi} - |\delta||p|\cos\theta_{\delta\gamma}\cos\theta_{p\gamma})}{|\phi|(4|\phi||\gamma| - |\delta||\eta|\cos\theta_{\delta\gamma}\cos\theta_{\eta\phi})} \tag{19}$$

and

$$\alpha_B^{sep} = \frac{|\phi|(2|p||\gamma|\cos\theta_{p\gamma} - |\eta||k|\cos\theta_{\eta\phi}\cos\theta_{k\phi})}{|\gamma|(4|\phi||\gamma| - |\delta||\eta|\cos\theta_{\delta\gamma}\cos\theta_{\eta\phi})} \tag{20}$$

θ_{ij} is the angle between the vectors i and j. I use the equality: $ij = |i||j|\cos\theta_{ij}$[12].

Assume the Participation Constraints are met (as I do in all that follows), so the constrained solutions coincide with the 'partially unconstrained' ones.

3.2.1 Discussion

I provide some comparative statics for the results. I analyze the effect of changes in the parameters on α_A^{sep}. It is straightforward to accommodate my considerations for α_B^{sep}. Moreover, I assume that all marginal products are non-negative, that the cosines have values between 0 and 1, and that we have internal solutions[13].

1. $\frac{\partial \alpha_A^{sep}}{\partial |k|} > 0$. $\frac{\partial \alpha_A^{sep}}{\partial \cos\theta_{k\phi}} > 0$. The impact of $|k|$ represents a scaling effect. The higher the norm of the marginal impact of agent A's effort on principal A's objective, the more profitable it is, for the principal, to provide high-powered incentives. $\cos\theta_{k\phi}$ is a synthetic measure of the 'alignment' between the impact of scientist A on the objective and on the performance measure. The higher the alignment, the stronger the provided incentives. The incentive rate does not depend on the correlation among the objective and performance measures. For, this correlation is also affected by the covariance between the error terms, which the agent does not control. More precisely, the incentive rate depends on the collinearity between the marginal products of efforts. These results are similar to those in Baker (2003) and are intuitive.

[12]See Baker (2003) for the use of similar geometric notation.

[13]In strict sense, performing comparative statics requires that we keep all but one parameter constant. In this formulation, for example, this implies that, when we consider the change in the norm of a vector, we should move it in such a way that the alignments between that vector and the others with whom it interact are unchanged. This can be obtained by multplying both components of the vector by a positive constant. When, instead, we move one of the cosines, we should keep the norms of the vectors constant.

2. $\dfrac{\partial \alpha_A^{sep}}{\partial |\phi|} >< 0$. unlike the Baker's (2003) model, where an increase in the impact of effort on the performance measure, ceteris paribus, always affects the piece rate negatively, here the result is more complex. On the one hand, an increase in $|\phi|$ has a negative effect on the optimal piece rate, because the relative productivity of the agent's effort on the objective, with respect to the performance measure, is smaller. On the other hand, this will impact also the welfare of principal B through the presence of spillovers. Principal B is induced to supplement A in the provision of incentives. However, he can also exploit his strategic influence on A, and can *increase* α_B^{sep} 'not too much' in order to push principal A to *decrease* α_A^{sep} 'not too much'. Principal A therefore faces an incentive to move α_A^{sep} in the opposite direction than the one described above. The overall impact is ambiguous. We see, here, a first strategic consequence of the presence of spillovers.

3. $\dfrac{\partial \alpha_A^{sep}}{\partial |p|} < 0$. $\dfrac{\partial \alpha_A^{sep}}{\partial \cos \theta_{p\gamma}} < 0$. These are pure free-riding effects. For example, if $|p|$ increases, institution B will unambiguously increase his piece rate. Scientist B will supply higher effort, and this, if spillovers are present, will also benefit institution A. Therefore, institution A will find it optimal to get a free ride on B and reduce his costs by providing a lower piece rate.

4. $\dfrac{\partial \alpha_A^{sep}}{\partial |\delta|} >< 0$. $\dfrac{\partial \alpha_A^{sep}}{\partial |\eta|} > 0$. $|\delta|$ has an ambiguous impact, while the impact of $|\eta|$ is unambiguously positive. We can interpret these results as follows. First, an increase in $|\delta|$ has a negative 'information effect'. If $|\delta|$, a measure of the contribution of agent B to the performance measure X of principal A, is high, then the contribution of agent A to X (on which she is paid) is relatively smaller. Therefore, there is an incentive, for principal A, to reduce the marginal reward for agent A. A strategic effect, among the two principals, is also present. The tendency to reduce α_A^{sep} when $|\delta|$ increases, indeed, will induce principal B to respond with an increase in α_B^{sep}. Therefore, the effort provided by agent B will increase. This makes, on the other hand, an increase in the incentive rate for agent A less costly, since principal A benefits also from the increased effort of agent B.

For the same reason why $|\delta|$ positively affects α_B^{sep}, so $|\eta|$ does with respect to α_A^{sep}. Notice, also, that the impact of $|\delta|$ and $|\eta|$ on α_A^{sep} is asymmetric. If $|\eta| = 0$, $|\delta|$ still has an impact. More precisely, only the negative, informational impact of $|\delta|$ will survive. When $|\delta| = 0$ the magnitude of $|\eta|$ is irrelevant for the definition of the optimal α_A^{sep}. The opposite holds for α_B^{sep}. This shows how important the informational impact of $|\delta|$ on α_A^{sep} is, in order to put in motion the strategic effect of $|\delta|$ itself and $|\eta|$.

The presence of an informational and strategic role for the spillovers on the performance measures is a novel finding in the principal-agent literature. These spillovers tell the principal about the goodness of performance measure in inferring the effort of his own agent. They also give information on how the other principal will behave. These findings also contribute to more qualitative studies, since the majority of them have not appropriately explored how knowledge spillovers affect incentives and incentive provision.

The role of the cosines can be interpreted in similar fashions as those of the effects discussed above. They can also be seen as affecting the magnitude (and the direction) of the impact of the various norms of vectors just described. Some alignment among the various marginal productivities is necessary to make these productivities have some impact.

To summarize:

1. The presence of spillovers is crucial in order to generate strategic interaction among principals. Each principal is affected also by the action of the other agent, and therefore by the incentive scheme defined by the other principal. If the spillover vectors δ and η are equal to zero, then:

$$\alpha_A^{sep} = \frac{|k|}{|\phi|}\frac{\cos\theta_{k\phi}}{2} \tag{21}$$

$$\alpha_B^{sep} = \frac{|p|}{|\gamma|}\frac{\cos\theta_{p\gamma}}{2} \tag{22}$$

There is no strategic interaction among the principals. Each piece rate depends only on the parameters of 'its own principal'. Moreover, the comparative statics are unambiguous for each of the terms in the expressions. Notice also the different role of the marginal impacts of spillovers on the objectives and on the performance measures. While the impact of agent j on the objective of principal i is easily interpretable as something that directly affects payoffs and social welfare, the 'spillovers' on the performance measures may convey information in the definition of the appropriate incentives. If spillovers are also present at the level of performance measures, then the optimal incentives will be altered.

2. The fact that the incentives provided by principal j may affect also principal i will give rise to temptations to get a free ride on each other's incentive scheme.

3. More subtly, each institution cannot provide incentives to the scientist affiliated to the other institution in a direct fashion: it can influence her behavior only through the influence on the other institution's choice of the optimal incentive scheme. This, as we will see, is an interesting difference also from the common agency case, where each institution can directly influence the same (unique) agent.

3.3 Common agency

Let us now assume that, instead of two different and separated populations of scientists, a unique population is allowed to respond to both kinds of incentives directly. I assume a case, so to use Bernheim and Whinston's (1986) parlance, of 'intrinsic common agency': the agent is bound to both communities (see also Mezzetti (1997)). She will accept both contracts or neither contract. Therefore, for each principal, the participation constraint to account for is with respect to the agent exiting both relations and earning her outside option.

Each principal proposes a contract very similar to the previous ones:

$$W_A = \alpha_A X \tag{23}$$

$$W_B = \alpha_B Y \tag{24}$$

α_A and α_B are the piece rates. X and Y are as in expressions (7) and (8). The agent maximizes her expected payoff: $E(W_A + W_B - C)$ with respect to e_1 and e_2. The IC constraints for the principals will be:

$$e_1 = \alpha_A \phi_1 + \alpha_B \gamma_1 \tag{25}$$

$$e_2 = \alpha_A \phi_2 + \alpha_B \gamma_2 \tag{26}$$

Each optimal choice of effort is now an average of the piece rates, weighted by the marginal effects of that particular kind of effort on the performance measures. In addition to the distortion in the marginal products, another source of misalignment between each principal and the agent comes from the agent taking directly into account the incentives defined by the other principal[14]. This is consistent with the distinction between 'the motives of the individual scientists and the motives of the firms that employs them' made by Rosenberg (1990, p.169; see also

[14] Since effort choices come from an average of different rewards, this may also reduce the heterogeneity among individuals.

Nelson (1962, p.573))[15]. Since effort choices come from an average of different rewards, this may reduce the heterogeneity among individuals.

Principal A solves

$$Max_{\alpha_A}\{E(\Pi_A) = E(K - \alpha_A X)\} \text{ subject to (25) and (26)} \tag{27}$$

Principal B solves

$$Max_{\alpha_B}\{E(\Pi_B) = E(P - \alpha_B Y)\} \text{ subject to (25) and (26)} \tag{28}$$

simultaneously. Substitute (3), (7), (25) and (26) into (27); and (4), (8), (25) and (26) into (28). Determine the (necessary and sufficient) first-order conditions of (27) with respect to α_A, and of (28) with respect to α_B. We obtain the best response functions:

$$\alpha_A = BR_A(\alpha_B) = \frac{k\phi}{2|\phi|^2} - \frac{\gamma\phi}{2|\phi|^2}\alpha_B \tag{29}$$

$$\alpha_B = BR_B(\alpha_A) = \frac{p\gamma}{2|\gamma|^2} - \frac{\gamma\phi}{2|\gamma|^2}\alpha_A \tag{30}$$

The Nash equilibrium piece rates are:

$$\alpha_A = \frac{2|k|\cos\theta_{k\phi} - |p|\cos\theta_{p\gamma}\cos\theta_{\phi\gamma}}{|\phi|[4 - (\cos\theta_{\phi\gamma})^2]} \tag{31}$$

and

$$\alpha_B = \frac{2|p|\cos\theta_{p\gamma} - |k|\cos\theta_{k\phi}\cos\theta_{\phi\gamma}}{|\gamma|[4 - (\cos\theta_{\phi\gamma})^2]}. \tag{32}$$

3.3.1 Discussion

Again, I discuss the comparative statics of the results and focus on α_A.

1. $\frac{\partial\alpha_A}{\partial|k|} > 0$. $\frac{\partial\alpha_A}{\partial|\phi|} < 0$. $\frac{\partial\alpha_A}{\partial\cos\theta_{k\phi}} > 0$. For $|k|$ and $\cos\theta_{k\phi}$ we have the same unambiguous effects as we obtained for the exclusive dealing case. Here, however, also the effect of $|\phi|$ is unambiguous. Both principals exert a direct influence on the same agent, and this eliminates a gaming component of this parameter.

[15] The expected payoff of the scientist may also be written as: $E[W_B - (C - W_A)]$. So, from the point of view of the firm (for example), the scientists has a reduction in her cost of effort, because of the reward from academia. This is similar to what has been called 'taste for science' (see Stern (1999)). Unlike the majority of existing treatment, I endogenize the relevance of such taste, through the strategic interaction among prioncipals.

2. $\frac{\partial \alpha_A}{\partial |p|} < 0$. $\frac{\partial \alpha_A}{\partial \cos \theta_{p\gamma}} < 0$. We have a free-riding effect from an increase in the norm of marginal impact of effort on the other principal's objective measure. Principal A will rely on B strengthening incentives for the scientist, and this will benefit A since the effort of the scientist impact also his objective Equivalently, we can say that A lowers the piece rates since B will get relatively more benefits from the agent's effort. Stephan (1996), commenting on the frequently noted flat profile of academic salaries along the career of a university professor, argues that a more complete account of this fact should consider the presence of outside activities, especially for senior faculty. Stephan and Everhart (1998) offer some evidence on these additional sources. The symmetric effect of $|k|$ on α_B is consistent with Stern's (1999) finding of scientists willing to accept lower compensation from business firms, if they are allowed to interact with the Republic of Science[16]. The impact of an increase in $|p|$ depends on the alignment between p and γ. If the performance measure used by principal B is 'useless' (i.e. very poorly aligned with p), then B will provide very low incentives for Y, and so principal A will not be induced to significantly reduce α_A even if the marginal impact of effort on P is very high. When $\cos \theta_{p\gamma} = 0$, $|p|$ is irrelevant for A.

3. $\frac{\partial \alpha_A}{\partial \cos \theta_{\phi\gamma}} >< 0$. The optimal level of α_A depends also on the alignment between the vectors of marginal productivities of efforts on the two performance measures. This alignment has an ambiguous effect. On one hand, an increase in $\cos \theta_{\phi\gamma}$ will reinforce, ceteris paribus, the incentive to free ride: the impact of the two kinds of effort on X is collinear to the impact on Y, and an increase in the piece rate on Y will induce a behavioral response (in term of balance between the two kinds of effort) similar to what A can get by setting his piece rate. However, suppose that $|p|$, or $\cos \theta_{p\gamma}$, are small. Now, principal B will try to mute incentives. The behavioral response of the agent would be harmful to principal A, and more so when ϕ and γ are collinear: if $|k|$ and $\cos \theta_{k\phi}$ are sufficiently high, A will prefer to supplement B in the provision of incentives. Moreover, notice that $\cos \theta_{\phi\gamma}$ enters the expression of α_B in the same fashion. Its effect is symmetric on the two principals, who will therefore reduce their piece rates by a smaller amount. The alignment between the performance measures may serve, therefore, to

[16] An increase in $|k|$ may also be seen as an increase in the ability of the scientist. Such increase may raise the equilibrium profits of the business firm, in common agency, even when its optimal piece rate goes down (see the numeric case 1 as an example of an increase in the profits of institution A when $|p|$ goes up). This is consistent with Stern's (1999) claim that firms will be more willing to let better scientists interact with the scientific community.

mitigate the tendency to free ride, in order to exploit the advantages that the same kind of efforts have on both objectives. Even in a non-cooperative setting, the principals are somewhat internalizing part of the externalities. If $\cos\theta_{\phi\gamma} = 0$, then $\alpha_A = \alpha_A^{sep}$ and $\alpha_B = \alpha_B^{sep}$ when spillovers are absent. Some level of congruity between the performance measures makes the common agency case interesting. The principals are concerned with the behavioral response of the same agent to incentives defined by different institutions, and look at how such response will differ, if provided by themselves or by the competing principal. In the exclusive dealing case, instead, the principals provide 'direct' incentives to separate agents. Each principal is not interested in how the piece rate that the other principal is providing to an agent will be similar to the one he would provide that very same agent.

3.4 A summary of the main differences between the exclusive dealing and the common agency cases

I now summarize the findings of my analysis, concerning the two different forms and degrees of interaction among different institutions, in the performance of research activities.

1. In the exclusive dealing case, the presence of spillovers of one agent's activity on the other principal's performance measure are crucial to have strategic interaction among principals, since each principal cannot influence the agent affiliated to the other institution directly. If the spillovers were only on the objective function, the optimal piece rates would be defined, by each principal, without any considerations of what the other principal does. This is clearly an extreme case, but a useful one to begin to understand the difference between interactions at the level of the objectives (i.e., presence or not of a multiplicity of institutional goal) and interactions at the level of the incentive system, especially when incentives cannot be defined directly on the basis of the objective measures.

2. A low impact of spillovers produces, in the exclusive dealing case, low interaction and, potentially, high duplication of effort. This will not happen in the common agency case since the same agent's effort directly affects both institutional objectives. On the other hand, the exclusive dealing case will not suffer from some of the 'distortions' deriving from strategic interaction (like an excessive tendency to free ride), and may produce a better balance in the performance of different activities.

3. While, in the exclusive dealing setting, the influence that principal i exerts on agent j is an indirect one (i.e., it occurs only through the strategic interactions among principals), in common agency we see both an indirect and a direct influence. Each principal directly affects the

unique team of agents; the presence of the direct impact makes the indirect influence different from the separation case. In figure 2, the solid lines represent direct influences, while the dotted lines represent indirect influences.

4. The informational role of spillovers, which we have discussed in the exclusive dealing case, is a relatively novel finding. This role is lost in common agency, because of the absence of a multiplicity of actors affiliated to different institution and responding to different incentive schemes.

5. In both institutional settings, the impact of changes in the parameters of the 'true' objective yields unambiguous comparative statics. By contrast, the effect of the parameters in the performance measure is, in some cases, more subtle to understand and, even when monotone, is typically not linear. This is another way to see the differences between interaction in objectives and incentives.

The presence of several parameters and of some non-linearities makes it difficult to assess in general terms the desirability, from a social point of view, of one or the other setting. I therefore proceed with some numerical examples.

3.5 Some numerical examples

I propose three numerical examples to explore how different values of the parameters, or different environments, affect the results. These exercises are meant to be just evocative and to 'check' the ability of my model to identify the determinants of the desirability of the two settings described. I report, for each of the configurations, the value of the parameters, and graphs representing the levels of the piece rates, the payoffs of the two principals, and the total welfare (sum of the payoffs of all the actors)[17].

1. In case 1, we have high alignment between the objective and the related performance measure for principal A, and a smaller impact of the two activities, in particular e_2, on the objective of principal B, the business sector. Spillover parameters are all positive and relatively small. The marginal impact of basic research effort on the B's objective (p_2) is increasing. Such increase has an effect on both the magnitude of the marginal impacts and the alignment between objectives and perfor-

[17] As expected, all cases have a level of total surplus below the first best (coming from joint maximization of payoffs, and observability of effort choices). For the way I set up the model, we may have different levels of first-best in the case of one and two agents. If spillovers were absent, then the one-agent first-best will dominate. See Mezzetti (1997) for a similar result (due, in his case, to complementarities of effort choices). If spillovers on the objectives are substantial, the order may change. In any case, in the non-cooperative setting with asymmetric information I set up, the second-best ordering can be different from the first-best ordering.

mance measures. When p_2 increases, the common agency case tends to dominate. For a very small p_2, the free riding incentive of principal B is high in both configurations, and this yields a low piece rate α_B, which in turn reduces the effort provided. When p_2 moves up, the optimal α_B and α_B^{sep} increase. The decrease in the α_As is limited. The no-duplication effect, however, tends to prevail with respect to the spillovers, which are relatively small. This configuration may represent a case in which, initially, basic research activities do not have a substantial role in the generation of profits, while they are important in the academic regime for the creation of knowledge. In these conditions, mixing the two worlds by allowing scientists to respond directly to both sets of incentives may reduce welfare, since they will find it optimal to contain effort in basic research. Once the impact of e_2 grows also in business activities, then common agency, as defined here, would reduce duplication of effort. This would be particularly important if the application of such research requires the direct employment of a given scientist, and cannot be easily transferred among different researchers (Zucker et al. (1998)). This case is captured by the small values of the spillover parameters.

We can think of a shift in the scientific and technological paradigm in an industry that leads to an increase of the role of basic research in the generation of economic rents without a reduction, in absolute value, of the role of applied research. We can also think of the presence of a handful of skilled scientists whose knowledge is difficult to transfer. Consider, as an example, the case of the pharmaceutical industry after the emergence of biotechnology[18]. Or, at cross sectional level, think of the difference between science-based industries and sectors where basic science is less profitable (see Pavitt (1984) and the distinction between Modes I and II of knowledge production in Gibbons et al. (1994)).

2. In case 2, it is instead the impact of e_2 on the patent performance measure Y, i.e. γ_2, that varies. Initially, the increase in γ_2 produces also an increase in the alignment between the patent performance measure and the economic profits, but then $\cos\theta_{p\gamma}$ tends to decrease. Moreover, $\cos\theta_{\phi\gamma}$, the measure of the alignment between the performance measures, is increasing. These two facts produce a strong reduction in α_B, while the effect on α_B^{sep} is non-monotone, witnessing the different kinds of consequences, from a change in $|\gamma|$, in the two configurations. After an initial decrease, the optimal α_A goes up, and this allows to limit the negative effect of the lower powered incentives provided by principal B. The impact on α_A^{sep} is very limited, because of effects moving in different directions. Total welfare in common agency is higher than in

[18] Powell and Owen-Smith (1998), Zucker et al. (1998), Henderson et al. (1999), Cockburn and Henderson (2000), Cohen et al. (2002),

the exclusive dealing case for small values of $|\gamma|$, and lower otherwise. The strategic distortion concentrated on only one agent ends up being deleterious for higher levels of $|\gamma|$. This example is interesting in that we can see clearly how, in the two settings, optimal incentive provision responds differently to a given change.

3. In case 3, I make $|\eta|$ increase. Recall that $\eta = (\eta_1, \eta_2)$ represents the marginal impacts of the effort of agent A on the performance measure used for rewarding agent B. It is a form of spillover, but not on the 'true' objective. As I discussed above, this may have more complex and ambiguous effects, because of the informational as well as strategic impact of such change. In this particular case, an increase in spillovers reduces the welfare in the exclusive dealing case, because strategic and informational distortions prevail on the direct beneficial effect. This case pushes us to be clearer on what is meant by spillover, in a setting when imperfect performance measures are employed to reward agents. The common agency case may be preferable not only when there is little spillover at the level of the objective measures, if agents work separately. The common agency case may prevail also because the strategic distortions among principals, in exclusive dealing, can be even greater. Moreover, strategic distortions in exclusive dealing may originate from some parameters that, instead, do not affect the common agency setting.

4 Conclusion

In this paper, I have proposed a formalization of some recent insights in the economic study of scientific activities. The focal theme has been the desirability of interactions between not-for-profit organizations and business-oriented institutions, in the performance of scientific activities. These interactions have been viewed traditionally in terms of 'informal' knowledge spillovers. More recently, the interaction between business and academia has evolved toward more explicit and direct forms. Studies from different approaches have expressed concerns about this process, but have also highlighted some opportunities.

I have tackled the issue from a principal-agent perspective. I have used the specific case of the provision of incentives to scientists to blend two principal-agent approaches that, to date, have not been combined: multi-task agency models with distorted performance measures, and common agency models. The presence of distorted performance measures is consistent with the difficulties in evaluating scientific effort. I compared a case of common agency, where scientists directly respond to different communities, to a setting where different teams work for different institutions, and the influences are through knowledge spillovers. The main effects of these interactions has been referred to as: scaling, alignment, free riding, information, duplication. Some of these effects, like scaling, alignment and free riding, are present in both configurations. The information effect I have considered emerges when different teams are operating, and knowledge spillovers occur between them. The absence of duplication of effort is a potential advantage of a common agency setting. The second-best level of welfare may be greater in either configuration, according to the values of the parameters. I also tried to relate different values of the parameters to the features of some industries.

4.1 Limitations of the model

The model I propose is very simplified. My characterization of the mechanisms of production of knowledge and economic rents from research activities is crude. For example, there is no interaction between basic and applied activities, since they enter the production functions additively. Other limitations are the separability of the disutility function, and the consideration of only formal agreements: informal-relational contracts and reputation concerns are likely to be important, especially in the Scientific Community[19]. It would be interesting to explore settings that imply direct strategic interaction also among agents. Finally, it would be valuable to explore more precise empirical predictions of the model..

4.2 Main insights

Despite the limitations, my model conveys a few interesting, and somewhat novel, insights.

1. My joint consideration of incentive issues and knowledge spillovers provides a more comprehensive view of the relations between the nature of knowledge and the institutional norms that affect its production.

2. A major insight concerns the necessity to take into account several incongruities between an agent's actions and the desired outcomes. These incongruities can differ in exclusive dealing and in common agency, and more generally depends on the kind of institutional arrangements.

3. My model also helps to distinguish between the impact of differences in the objective functions and in the provided incentives. I allow for the presence of both institutional diversity and institutional interaction: institutional objectives are kept different, but the interaction takes place in the optimal definition of incentives and in the way scientists respond to them. The (assumed) difference in objectives is important to stimulate different kinds of activities a society cares about. However, the provision of incentives to fulfill these objectives, when effort is

[19] On this last point, see Baker et al (1999), and also some interesting considerations about academic activities and 'public trust' in Argyres and Liebeskind (1998).

hard to measure, may add some complications in the way institutional differences translate into social welfare.

4. My model encompasses different forms of interaction, more and less formal, in the same theoretical framework and in a relatively parsimonious and tractable way. This is helpful for identifying, in a consistent way, the drivers of the results and for comparing the different cases.

5. Finally, the model attributes an active role to the scientific community, and tries to substantiate generic references to a 'taste for science' on the part of researchers.

Issues of industry-university relationship are crucial for public policy as well as for the management of innovation, and have been treated from several perspectives, theoretical and empirical. My framework can offer an additional, and potentially fruitful, perspective to analyze these topics.

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6 Figures

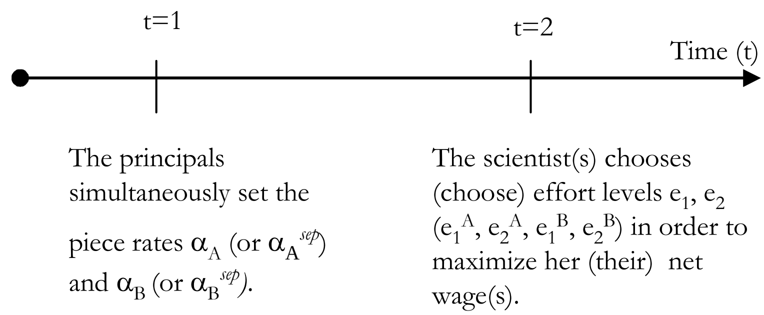


Figure 1: The timing of the games

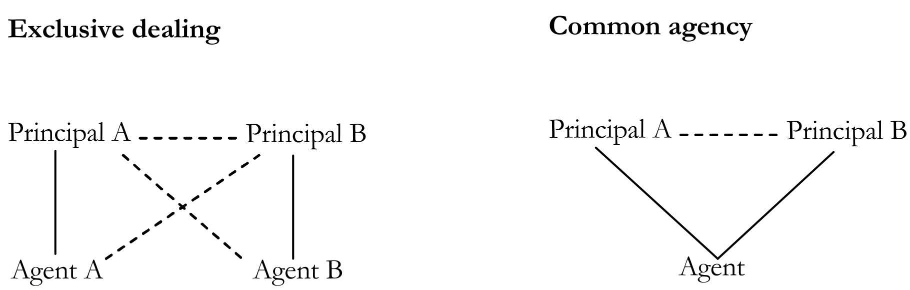
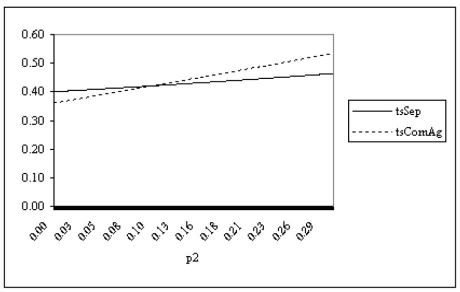


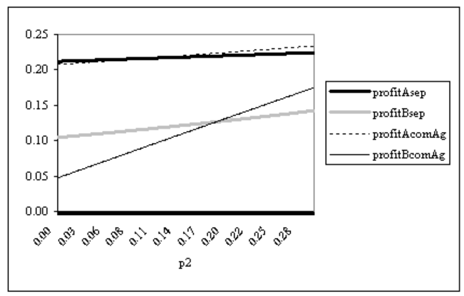
Figure 2: A representation of the differences in strategic interaction in the cases of exclusive dealing and common agency

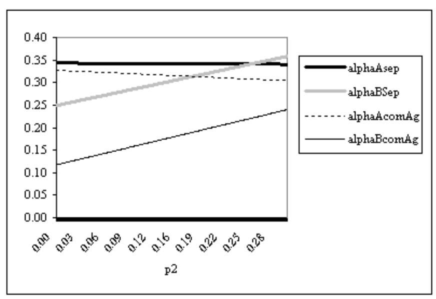
Numerical examples

Case 1

Parameter values: $k = (.17; .84)$; $\phi = (.25; 1.2)$; $p = (.5; variable)$; $\gamma = (.6; .35)$; $\beta = (.1; .1)$; $\delta = (.08; .08)$; $\sigma = (.12; .12)$; $\eta = (.12; .12)$



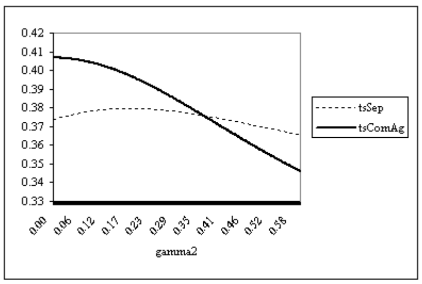


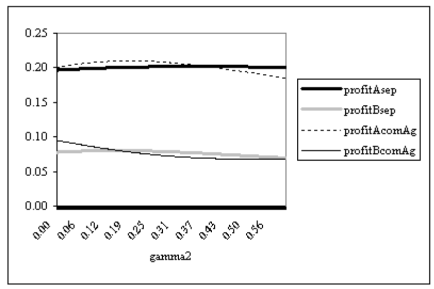


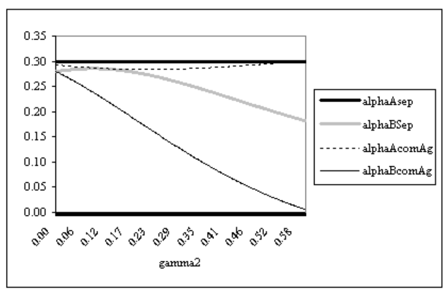
ts=total surplus

Case 2

Parameter values: $k = (.17; .84)$; $\phi = (.22; 1.4)$; $p = (.4; .1\ )$; $\gamma = (.6; variable)$; $\beta = (.05; .05)$; $\delta = (.05; .05)$; $\sigma = (.08; .08)$; $\eta = (.08; .08)$



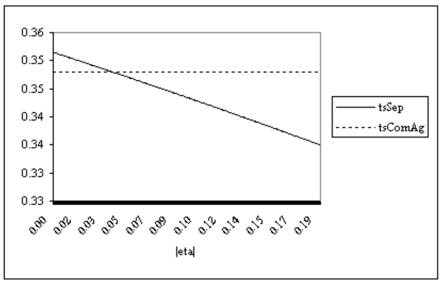


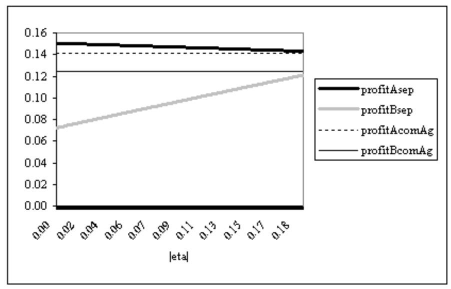


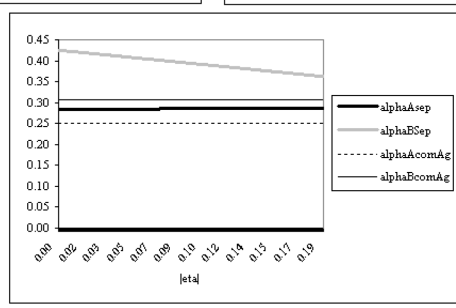
ts=total surplus

Case 3

Parameter values: $k = (.2; .6)$; $\phi = (.3; 1)$; $p = (.5; .2\ )$; $\gamma = (.6; .2)$; $\beta = (.13; .13)$; $\delta = (.12; .12)$; $\sigma = (.15; .15)$; $|\eta|$ variable







ts=total surplus

7 Appendix

7.1 Proof of results (31) and (32)

The proofs for results (19) and (20), the exclusive-dealing case, and for results (31) and (32), the common agency case, follow the same reasoning. Therefore, I provide only the proof for (31) and (32).

Notice that the objective function is concave, so the first order conditions (f.o.c.) are necessary and sufficient. The f.o.c. are:

$$\frac{\partial}{\partial \alpha_A}\{k_1(\alpha_A\phi_1+\alpha_B\gamma_1)+k_2(\alpha_A\phi_2+\alpha_B\gamma_2)-\alpha_A[\phi_1(\alpha_A\phi_1+\alpha_B\gamma_1)+\phi_2(\alpha_A\phi_2+\alpha_B\gamma_2)]\}=0$$

$$2\phi_1^2\alpha_A+2\phi_2^2\alpha_A=k_1\phi_1+k_2\phi_2-\gamma_1\phi_1\alpha_B-\gamma_2\phi_2\alpha_B \tag{33}$$

$$\frac{\partial}{\partial \alpha_B}\{p_1(\alpha_A\phi_1+\alpha_B\gamma_1)+p_2(\alpha_A\phi_2+\alpha_B\gamma_2)-\alpha_B[\gamma_1(\alpha_A\phi_1+\alpha_B\gamma_1)+\gamma_2(\alpha_A\phi_2+\alpha_B\gamma_2)]\}=0$$

$$2\gamma_1^2\alpha_B+2\gamma_2^2\alpha_B=p_1\gamma_1+p_2\gamma_2-\gamma_1\phi_1\alpha_A-\gamma_2\phi_2\alpha_A \tag{34}$$

This gives the reaction functions in (29) and (30), and, from them, we obtain (31) and (32).

7.2 A more general case with affine schemes - Multiple equilibria in common agency

In this note, I show the complications that derive from assuming affine schemes (fixed salary plus piece rate, more commonly used in the literature), in the (intrinsic) common agency case.

Suppose the wage schemes take the form:

$$W_A=\tau_A+\alpha_A X \tag{35}$$

$$W_B=\tau_B+\alpha_B Y \tag{36}$$

where τ_A and τ_B are the fixed salaries. The agent's problem is the same as before. Consider the principals' problem. Principal A solves:

$$Max_{\alpha_A}\{E[\Pi_A]=E[K-(\tau_A+\alpha_A X)]\} \tag{37}$$

subject to

$$e_1=\alpha_A\phi_1+\alpha_B\gamma_1 \tag{38}$$

$$e_2=\alpha_A\phi_2+\alpha_B\gamma_2 \tag{39}$$

$$E(W_A+W_B-C)\geq 0 \tag{40}$$

I now consider explicitly the participation constraint. The reason will be clear shortly.

Principal B solves:

$$Max_{\alpha_B}\{E[\Pi_B] = E[P - (\tau_B + \alpha_B Y)]\} \tag{41}$$

subject to the same constraints.

The Lagrangian for principal A is therefore:

$$\Lambda_A = K - (\tau_A + \alpha_A X) + \lambda_A[W_A + W_B - C] = \tag{42}$$

$$\begin{aligned} &k_1(\alpha_A\phi_1 + \alpha_B\gamma_1) + k_2(\alpha_A\phi_2 + \alpha_B\gamma_2) \\ &-\{\tau_A + \alpha_A[\phi_1(\alpha_A\phi_1 + \alpha_B\gamma_1) + \phi_2(\alpha_A\phi_2 + \alpha_B\gamma_2)]\} \\ &+\lambda_A\{\alpha_A[\phi_1(\alpha_A\phi_1 + \alpha_B\gamma_1) + \phi_2(\alpha_A\phi_2 + \alpha_B\gamma_2)] + \tau_A \\ &+\alpha_B[\gamma_1(\alpha_A\phi_1 + \alpha_B\gamma_1) + \gamma_2(\alpha_A\phi_2 + \alpha_B\gamma_2)] + \tau_B \\ &-\tfrac{1}{2}(\alpha_A\phi_1 + \alpha_B\gamma_1)^2 - \tfrac{1}{2}(\alpha_A\phi_2 + \alpha_B\gamma_2)^2\} \end{aligned} \tag{43}$$

Principal A solves the f.o.c. with respect to α_A, τ_A and the Lagrange multiplier λ_A. The first order condition for τ_A gives: $\lambda_A = 1$. Therefore, the participation constraint is binding. The f.o.c. for α_A yields:

$$\alpha_A = \frac{|k|}{|\phi|}\cos\theta_{k\phi} \tag{44}$$

With a similar procedure for principal B, we get $\lambda_B = 1$ and:

$$\alpha_B = \frac{|p|}{|\gamma|}\cos\theta_{p\gamma} \tag{45}$$

As for the fixed salaries, we need to solve:

$$\tau_A + \alpha_A X + \tau_B + \alpha_B Y - C = 0 \tag{46}$$

for principal A, and

$$\tau_A + \alpha_A X + \tau_B + \alpha_B Y - C = 0 \tag{47}$$

for principal B, with respect to τ_A and τ_B (all the other terms are now functions of known, exogenous parameters). The two expressions are identical and we cannot find a unique solution. Notice that now the strategic interaction is transferred to the fixed salary. Because of these complications, I opt, in my model, for purely linear schemes and internal solutions. For consistency, I do the same for the exclusive dealing case.

The absence of a fixed component of the salary also implies that the principals cannot separate between creating incentives to increase the surplus, through the piece rate, and sharing the generated surplus, through the fixed component (see Holmstrom and Milgrom (1987)). Now, both functions have to be performed by the piece rate in the 'pure linear' scheme. This may imply, for example, that the principals prefer to leave to the agent some utility above her reservation level .