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The Hay and the Carrot: A Model of Corporate Sponsoring of Academic Research

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The Hay and the Carrot
A Model of Corporate Sponsoring of Academic Research

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Abstract

In a moral hazard model with relationship-specific investment ("hay") and limited liability (no "stick"), we compare two institutional regimes: one without, and one with, ex-post incentives ("carrot"). We examine the welfare implications of introducing "carrots". We use this model to analyze corporate sponsoring of academic research. Under restrictive technological assumptions, the introduction of carrots meets certain efficiency criteria and cannot make the agent (researcher) worse off. These results no longer hold once we allow for a "bang-for-your-buck" effect - which occurs when the researcher's following the sponsor's preferred strategy results in the principal (sponsor) being able to achieve the same results with fewer investment dollars - in conjunction with a concave value function for the sponsor. In this case, the introduction of carrots may be inefficient and may make the agent worse off. However, if the agent is a monopolist, a renegotiation-proof contract implies that the agent can never be made worse off by the introduction of carrots, and carrots never reduce social welfare.

1 Introduction

This paper examines a principal-agent model with moral hazard where negative ex-post incentives ("sticks") are ruled out, while an ex-ante relationship-specific investment ("hay") is a necessary precondition for any value creation. As we shall see, the agent (and society) can, in such a setting, be made worse off by the introduction of positive ex-post incentives ("carrots"). It is natural to extend the stick-and-carrot metaphor - commonly used in discussions of incentives - to include hay. Think of yourself as a horse owner. You can use sticks or carrots to incentivize the horse. However, hay is a prerequisite for the horse to be able to do anything at all. The importance of relationship-specific investments is recognized in the literature on the holdup problem (e.g. Grout 1984, Hart & Moore 1988). In contrast to this literature, in our model, specific investment is contractible, implying that there is no holdup problem. However, due to the moral hazard feature, underinvestment may still occur.

The asymmetry between sticks and carrots is by now well-established; it has been demonstrated experimentally (e.g. Andreoni et al. 2003). We employ the limited-liability assumption - the extreme case where sticks are ruled out entirely - for two reasons. First, we wish to highlight the relationship between the use of hay and the use of carrots. Second, it seems to be realistic in some real-world settings.

Our model captures some key characteristics of at least one type of real-world interaction: corporate sponsoring of nonprofit research. First, commercial credit is typically unavailable to fund nonprofit research, as it is not geared towards yielding appropriable cash flows. Thus, upfront sponsoring (hay) is an indispensible precondition for research activity. Second, nonprofit researchers' activities tend to be very difficult to monitor or control. The researcher may use a research strategy that will be beneficial for her, but does not lead to an invention profitable for the sponsor.[1] Hence the moral hazard setting may be appropriate. Third and finally, the sponsor-researcher relationship is a delicate one, subject to public scrutiny. Corporate sponsors are vulnerable to charges of exploitation which might tarnish their reputation. Thus, in reality a researcher typically cannot be punished for an unsuccessful research project. This feature is captured by the limited-liability assumption (introduced to the literature by Innes 1990; extended by Park 1995): an incentive contract cannot include monetary payments from the researcher to the sponsor for any contingency.

In recent decades, universities and other nonprofit research institutions have turned increasingly to corporate funding sources to supplement their research budgets. Many intellectuals and academics have mixed feelings about this trend. Is the universities' grand mandate to expand and transmit knowledge for the public good being compromised? A lively and wide-ranging debate is addressing this and related questions (Geiger 1992; Press & Wash-

[1] The seminal articles on moral hazard where the methodology used in this paper was developed looked at insurance markets (Mirrlees, 1975) or taxation (Guesnerie and Laffont, 1979). Holmstroem (1979) and Grossamn and Hart (1983) explore optimal incentive contracts with moral hazard in general settings.

burn 2000; Bok 2003). In this debate, one issue may have been overlooked: The relationship between ex-ante research sponsoring and ex-post incentives. One important aspect of the commercialization of academic research is an increased reliance on ex-post incentives. These may take a variety of forms, including for example intellectual property licensing arrangements (encouraged in the United States through the Bayh-Dole Act - see Mowery et al. 2001) or contractual 'milestones' that qualify for follow-up funding. Academic policymakers have significant discretion in encouraging or restraining the use of such incentives.

Consider the introduction of ex-post incentives into an academic research environment that so far has relied on upfront funding. On the face of it, the new incentive instrument is a good thing for all parties involved: It brings in extra money, and if the contract is not consistent with the academic institution's mission, it can always be refused. However, is it possible that the new incentive instrument serves as a substitute for ex-ante funding? Could the latter be reduced to the extent that the introduction of ex-post incentives actually harms the institution's objectives? Could society suffer as a result? We employ a highly stylized moral hazard model to address these questions. Jensen & Thursby (2001) also employ a moral hazard model to analyze university-industry relations. However, their focus is different. They are concerned with downstream development of university inventions; in their model, the private-sector licensee is the agent. In the present model, it is the university researcher who is the agent. In our model, the agent's non-contractible choice variable is his choice of research strategy. This is our counterpart of the 'effort' variable in the moral hazard literature.

This paper's setup is as follows. We first describe the 'baseline' model, derive its social optimum, and analyze the 'benchmark' case in which the use of the ex-post incentive instrument is not permitted. We compare this to the case where it is permitted, and show that in the baseline model, the sponsor will never induce the researcher to carry out its own research agenda unless this agenda is socially superior, and the introduction of ex-post incentives cannot reduce welfare or make the researcher worse off. We then proceed to an alternative do the baseline model, in which the researcher's following of the sponsor's research agenda allows the latter to achieve the same results with a reduced investment (the 'bang-for-your-buck assumption'), and the sponsor is interested in obtaining a specific research result only. Under these altered technological assumptions, the sponsor may use the incentive instrument to induce a socially inferior research agenda; allowing the sponsor to use the incentive instrument may actually result in a reduction in overall welfare or the agent's welfare.

2 The Baseline Model

There exists a research project which may be profitable for two parties, a sponsor and a researcher. The researcher does not have the financial means to conduct the research project, while the sponsor does not have the know how. Therefore the two parties engage in a principal-agent relationship, where the sponsor is the principal and the researcher is the agent.

Suppose that the research project has a potential value V_s for the sponsor and V_r for the researcher. However, these potential values depend on the quality and infrastructure of the research environment, which are indexed by a scalar I. It is convenient to define the index I so that it is proportional to the researcher's payoff or 'value'. We can then consider two cases: first, the sponsor's value function may be proportional to I as well. Second, the sponsor's value function may be strictly concave - implying that it can be obtained from the researcher's value function through a strictly concave transformation. The first case is considered in the present section, and the second case in the next section. This use of the index I is a parsimonious way of expressing that the sponsor's value function may be either more concave than, or equally concave as, the researcher's value function.

The quality of the research environment depends on an up-front investment of the sponsor. The cost to generate a research environment I is denoted $C(I)$. We assume the cost to increase in I. Additionally, we assume that further improving the environment gets more expensive when the quality of the environment increases:

$$\begin{aligned} C(0) &= 0, \quad C'(0) = 0 \\ C'(I) &> 0, \quad C''(I) > 0 \end{aligned}$$

Without any up-front investment of the sponsor the potential value is zero for both the sponsor and the researcher:

$$\begin{aligned} V_s(I &= 0) = 0 \\ V_r(I &= 0) = 0 \end{aligned}$$

Due to the definition of I and to the fact that we are - for now - considering the case where the two value functions are equally concave, the values of the research project are assumed to depend linearly on the quality of the research environment:

$$\begin{aligned} V_s' &= \sigma, \quad V_r' = \rho \\ V_s'' &= 0, \quad V_r'' = 0 \end{aligned}$$

For simplicity we assume that the project can only be a success or a failure for the sponsor and for the researcher respectively. A successful project pays the potential value, while a failure pays nothing. To capture the different objectives of the researcher and the sponsor we assume that a failure for the researcher does not necessarily imply a commercial failure for the sponsor and vice versa. We denote the probability of success for the sponsor by p_s and the probability of success for the researcher by p_r. The joint probabilities are denoted by p_s^r, p_{-s}^r, p_s^{-r}, and p_{-s}^{-r}, where the minus sign denotes a failure. Then the distribution of outcomes for a project is given by:[2]

$$\begin{aligned} p_s^r &= p_s p_r \\ p_{-s}^r &= [1-p_s]p_r \\ p_s^{-r} &= p_s[1-p_r] \\ p_{-s}^{-r} &= [1-p_s][1-p_r] \end{aligned} \tag{1}$$

In order to incorporate the agency problem we allow the researcher to influence the success probabilities by his research strategy E. To keep the model simple we assume that the researcher has only two research strategies to choose from. Research strategy R is favorable for the researcher while research strategy S is the preferred strategy for the sponsor. A success for the researcher - say a publication in a top journal - becomes more likely if research strategy R is chosen. However, a research strategy tailored specifically for research publications reduces the probability of a commercial success for the sponsor. Vice versa a commercially orientated research strategy increases the likelihood of a success for a sponsor, whereas the probability for a research publication is reduced. We assume the effort cost for both research strategies to be the same. Then, without loss of generality, we can normalize these effort cost to zero.[3]

$$p_s(S) > p_s(R) \tag{2}$$

$$p_r(R) > p_r(S) \tag{3}$$

This setup creates a moral hazard situation. The sponsor would like the researcher to use his preferred research strategy S, but has no control over the choice of strategy. The researcher definitively wants to choose his favoured

[2] For simplicity we assume that the outcomes for the researcher and sponsor are drawn independently. Allowing for correlation seems to be more realistic, but complexifies the model without adding any insight.

[3] Error cost of zero may be interpreted as a univerity salary setting off the effort put into the research. Alternatively we can interpret the value of the project as nat of effort cost.

research strategy R. Which strategy is implemented depends crucially on the nature of the project and the contractual environment. It is clear that the research strategy cannot be contractible. No court could possibly decide without doubt whether a researcher used research strategy R or S. However, we may allow the sponsor and the researcher to sign a research contract which specifies transfers dependent on the outcome of the research project.

We restrict the outcome dependent transfers from the sponsor to the researcher to be non-negative for all outcomes. The reason for this assumption is the credit constraints of the researcher. Poor researchers do not have the financial means to pay fines for outcomes which are unpleasant for the sponsor. We believe that it is realistic to assume that the researcher is not able to pay transfers even if the project is a research success. Usually the payoff for a good research publication is non-monetary (reputation, status in the profession) or at least not immediate. This limited liability assumption restricts the possible incentive contracts for the sponsor.

We are thus ruling out the use of "sticks", which allows us to focus on the relationship between "hay" and "carrots".

Additionally, we assume both players to be risk neutral.

2.1 Timing

We now explain the timing of the principal-agent game.

Stage 1 The sponsor offers a contract containing a commitment of an up-front investment I and transfers depending on the outcome of the research projects. Denote the non-negative transfers from the sponsor to the researcher depending on the outcome as t_s^r if the project was successful for both, as t_s^{-r} if the project was only successful for the sponsor, as t_{-s}^r if the project was only successful for the researcher, and as t_{-s}^{-r} if the project was a total failure. As a benchmark case we will use an environment where incentive contracts are not possible (i.e. all transfers are zero).

Stage 2 The researcher accepts or rejects the proposed research contract. If he rejects the project does not go ahead and the game ends. This take-it-or-leave-it contractual environment gives all the bargaining power to the sponsor.

Stage 3 The sponsor makes the up-front investment I specified in the agreed contract.[4]

[4]We implicitely assume that the investment specified in the contract can be enforced by a court.

Stage 4 The researcher observes the investment and chooses the research strategy, which can be S or R. The chosen research strategy determines the probability distribution for the outcomes.

Stage 5 Nature determines the outcome of the project according to the probabilities in equation (1) and the restrictions in inequalities (3) and (2).

Stage 6 The payoffs for successful projects (V_r and V_s) are realized and the transfer specified in the incentive contract for the actual outcome realization is made.

2.2 Social optimum

Our model describes a world with imperfections. Due to a credit constraint the researcher has to find a sponsor. The credit constraint is rather due to the non-monetary nature of research success than due to imperfections in the capital markets. Therefore, we can view our researcher as a scientist with a preference for basic research.[5] Thus, we can regard the payoff for the researcher as an approximate measure of welfare created by positive externalities of basic research. The welfare created by the a commercial success of the research project can be approximated by the payoff of the sponsor. Consequently, we use the sum of the expected values of the research projects net of investment as a measure for social welfare.[6]

$$W = p_s(E)V_s + p_r(E)V_r - C(I)$$

Hence, the socially optimal investment for a given research strategy is given by:

$$C'(I) = \sigma p_s(E) + \rho p_r(E) \tag{4}$$

Note that the optimal investment is greater for research strategy R if

$$\sigma p_s(R) + \rho p_r(R) > \sigma p_s(S) + \rho p_r(S)$$

or

$$\rho \left[p_r(R) - p_r(S)\right] > \sigma \left[p_s(S) - p_s(R)\right], \tag{5}$$

[5] The preferences can be intrinsic or "induced" by the reward system in the profession.

[6] Not that it may be reasonable to use weights for the values in order to capture the possibility that the surplus created is not entirely internalized by the markets.

which can be interpreted as a situation where the gain of using the research strategy R for the researcher offsets the loss the sponsor has to endure. Consequently, condition (5) determines which research strategy is socially optimal. Defining the relative value of the project for basic research β as

$$\beta = \frac{\rho\left[p_r(R) - p_r(S)\right]}{\sigma\left[p_s(S) - p_s(R)\right]} \tag{6}$$

we can say that it socially optimal to use research strategy R, whenever $\beta > 1$. For $\beta < 1$ research strategy S is socially optimal. For $\beta = 1$ both research strategies are equally appropriate from the point of view of a social planer.

2.3 The benchmark case

As a benchmark case we look at the situation where transfer payments depending on the outcome of the project are not permitted. Then we can evaluate the influence incentive contracts have on efficiency and distribution of surplus between the two parties. Solving backwards shows that without any incentive contracts the researcher implements his preferred research strategy R, since the expected payoff from doing so is always greater than the expected payoff from implementing research strategy S:

$$EU_r(R) = p_r(R) \cdot V_r(I) > EU_r(S) = p_r(S) \cdot V_r(I) \quad \forall I$$

This is true because due to the assumption in equation (3) the probability of success for the researcher is always greater under the research strategy R. Given that the researcher always implements R the forward-looking sponsor will choose the investment in order to maximize his expected payoff under R:

$$\max_I \left\{p_s(R) \cdot V_s(I) - C(I)\right\}$$

which leads to the first order condition

$$C'(I) = \sigma p_s(R) \tag{7}$$

The second-order condition is satisfied by assumption. An interior solution is guaranteed with the assumptions made above

It is apparent that the optimal investment for the sponsor I increases with his probability of success $p_s(R)$. Additionally, the expected equilibrium payoff of the sponsor in the case that incentive contracts are impossible increases with $p_s(R)$. A corollary of this finding is that a sponsor always prefers the researcher to implement the research strategy S, which may give rise to the desirability of incentive contracts from the sponsor's point of view.

The expected payoff for the researcher is simply

$$EU_r = p_r(R)V_r(I_B^*)$$

where I_B^* is the investment that solves the first-order condition (7). (The subscript "B" refers to the "Benchmark" case.)

Note that the expected payoff in this case is positive.

2.4 Incentive contracts

In the previous section we established that the sponsor would like the researcher to pursue research strategy S. However, without any incentive instrument the researcher will choose to pursue his favoured research plan R. We will introduce two different contracting environments. First we allow contracts to be written contingent on the outcome of the researcher and the sponsor. However, later we argue that an environment where only the success of the sponsor is contractible is more realistic.

2.4.1 Outcomes for both are contractible

Suppose that the sponsor can offer a research contract which includes transfers (bonuses) depending on the outcome of the research project. Contracts that condition directly on the research strategy are not feasible, since a research strategy is hardly verifiable in court. Before the sponsor invests in the project he offers a contract, which specifies non-negative bonuses for the possible outcomes of the projects $T = (t_s^r, t_s^{-r}, t_{-s}^r, t_{-s}^{-r})$, where t_s^r is the payment in case the project is successful for both agents, while t_{-s}^{-r} denotes the payment for a failure for both parties.[7] The researcher can decide to accept or to reject this contract. If the contract is accepted, the sponsor invests, before the researcher conducts the research. In the case of rejection the game ends with a payoff of zero for both and the sponsor searches for another researcher. In a later section we will examine the case where the sponsor cannot find another researcher and in case of rejection renegotiation takes place.

A contract that provides an incentive for the researcher to follow the sponsor's preferred research strategy S has to satisfy the following incentive-compatibility constraint:

$$EU_r(S\,|T) \geq EU_r(R\,|T) \tag{IC}$$

[7] Note that due to the revelation principle no more complex mechanism has to be taken into account than a incentive compatible contract in the proposed form.

Simplifying the incentive constraint leads to the following condition

$$\begin{aligned}[p_r(R) - p_r(S)]\, V_r \leq [p_s^r(S) - p_s^r(R)]\, t_s^r + \left[p_s^{-r}(S) - p_s^{-r}(R)\right] t_s^{-r} \\ + \left[p_{-s}^r(S) - p_{-s}^r(R)\right] t_{-s}^r + \left[p_{-s}^{-r}(S) - p_{-s}^{-r}(R)\right] t_{-s}^{-r} \quad \text{(IC')}\end{aligned}$$

Instead of the usual participation constraint we use the constraint that all transfers have to be non-negative. This corresponds to our assumption that the researcher is credit-constrained and cannot be held liable for bad outcomes:

$$t_s^r \geq 0, \quad t_s^{-r} \geq 0, \quad t_{-s}^r \geq 0, \quad t_{-s}^{-r} \geq 0 \qquad \text{(IR)}$$

The sponsor wants to offer the cheapest incentive-compatible contract given the constraint above. It follows that the optimal transfer in the case that the project is only a success for the researcher has to be zero, since a positive t_{-s}^r would provide the wrong incentives as $p_{-s}^r(S) - p_{-s}^r(R) < 0$. There are three possible transfers to incentivize the researcher. The strongest incentives are provided by a transfer t_s^{-r}. If only such a transfer is used the transfer necessary is:

$$t_s^{-r} = \frac{p_r(R) - p_r(S)}{p_s^{-r}(S) - p_s^{-r}(R)} V_r$$

2.4.2 Only the sponsor's outcome is contractible

It is reasonable to assume that the researchers' outcomes are noncontractible. In the present model, including those outcomes as contractible items would imply that, as a result of the researcher achieving success on the academic front, his payoff would be lowered! The reason for this is that academic publications would count as evidence rendering it more likely that the researcher did not pursue the sponsor's agenda. Such a contract would be hard to 'sell' in public-relations terms for real-world sponsors. Moreover, the sponsor is likely to be more familiar with research outcomes that follow his own agenda, and is thus better placed to negotiate the inclusion of such outcomes in contractual provisions.

In this case the participation constraint stays the same, while the incentive constraint becomes

$$[p_r(R) - p_r(S)]\, V_r \leq [p_s(S) - p_s(R)]\, t_s + [p_s(R) - p_s(S)]\, t_{-s} \qquad \text{(IC2)}$$

It is obvious that $t_{-s} = 0$ is optimal, since due to $p_s(R) - p_s(S) < 0$ a positive t_{-s} has the wrong incentive effect. Therefore the cheapest incentive contract is given by

$$t_s = \frac{p_r(R) - p_r(S)}{p_s(S) - p_s(R)} V_r = \frac{\sigma}{\rho} \beta V_r \tag{8}$$

$$t_{-s} = 0 \tag{9}$$

If the sponsor chooses to offer this contract his optimal investment is determined by the following program:

$$\max_I \left\{ p_s(S) \left[V_s - \frac{p_r(R) - p_r(S)}{p_s(S) - p_s(R)} V_r \right] - C(I) \right\}$$

The first order condition becomes

$$C'(I) \geq \sigma p_s(S) \left[1 - \beta\right]. \tag{10}$$

Note that the optimal investment for a research project, which should be conducted with research strategy R from a social point of view ($\beta > 1$), never leads to a positive investment if the sponsor wants to enforce research strategy S.

Comparing the optimal investments if an incentive contract is used and if not we find that for

$$\beta > 1 - \frac{p_s(R)}{p_s(S)} \tag{11}$$

the quality of the environment I_c^* in the contract case is smaller than in the non-contract case I_B^*.[8] However, it is not clear whether the sponsor really wants to use an incentive contract. Recall that for $\beta \geq 1$ an incentive contract leads to $I = 0$, which leaves the sponsor with a zero payoff. The project is abandoned. However, by not offering a contract an investment of I_c^* is induced and the payoff for the sponsor is $p_r(R)V_r(I^*) - C(I^*) > 0$. Consequently, the sponsor does not offer a contract in this situation.

Proposition 1 *If a research strategy R is socially optimal ($\beta \geq 1$) the sponsor never induces S with an incentive contract.*

This positive result in terms of efficiency - a research project that should be tackled with research strategy R is never tackled with a research strategy S - brings up the question whether the possibility of incentive contracts always induces the research strategy S if it would be socially optimal. The answer is no. Only if beta is sufficiently small the sponsor chooses to offer an incentive contract in order to induce the optimal research strategy S.

[8] To see this recall that due to the properties of $C(I)$ $I < I'$ follows from $C'(I) < C'(I')$. Then comparing the first order conditions (10) and (7) gives the claimed result.

Proposition 2 *The sponsor only offers a incentive contract that induces research strategy S if $\beta \leq 1 - p_s(R)/p_s(S)$.*

Proof. We can write the difference between expected payoffs with an incentive contract and without as

$$\begin{aligned}\Delta EU &= EU_s(I_c^*) - EU_s(I_B^*) \\ &= \sigma\left(p_s(S)\left[1-\beta\right]I_c^* - p_s(R)I_B^*\right) - C(I_c^*) + C(I_B^*).\end{aligned}$$

Observe that this difference is equal to zero for $\beta = 1 - p_s(R)/p_s(S)$, since the term in brackets vanishes and since condition (11) implies $I_c^* = I^*$ and therefore $C(I^*) - C(I_c^*) = 0$. The sponsor is indifferent between using an incentive contract and not. Now suppose β increases above that level, due to a change in ρ, $p_r(R)$, or $p_r(S)$. Then the the change of the difference above is given by

$$\left.\frac{\partial \Delta EU}{\partial \beta}\right|_{I=I_c^*} = \sigma p_s(S)\left(\left[1-\beta\right]\frac{\partial I_c^*}{\partial \beta} - I_c^*\right) - \frac{\partial I_c^*}{\partial \beta}C'(I_c^*)$$

using the first-order condition gives

$$\left.\frac{\partial \Delta EU}{\partial \beta}\right|_{I_c^*} = -\sigma p_s(S) I_c^* < 0.$$

So for a $\beta > 1 - p_s(R)/p_s(S)$ the sponsor prefers not to offer an incentive contract.

For the other parameters that determine β, including σ, $p_s(S)$ and $p_s(R)$, a similar proof is available. ■

Corollary 3 *For $\beta \leq 1 - p_s(R)/p_s(S)$ the availability of an incentive contract improves welfare, while for $\beta > 1 - p_s(R)/p_s(S)$ the availability of incentive contracts leaves welfare unchanged.*

Proof. The second part is obvious. For $\beta > 1 - p_s(R)/p_s(S)$ the sponsor will not choose to offer a contract. So nothing changes to the situation where no contract is available. For $\beta \leq 1 - p_s(R)/p_s(S)$ the sponsor induces S by an incentive contract, which is socially optimal, since $\beta < 1$. Additionally, the quality of the research environment is weekly higher than without a contract (condition 11), but never higher than socially optimal. To see this compare the first-order conditions (4) and (10). So an incentive contract makes sure that for $\beta \leq 1 - p_s(R)/p_s(S)$ (a) the socially optimal research strategy is used and that (b) the quality of the research environment is closer to the optimum. ■

3 Alternative value functions: Concavity and Bang-For-Your-Buck

In this section, we attempt to express mathematically the differences between the objectives that the sponsor and researcher are likely to have. To this end, we develop an alternative function for the sponsor that express three features: First, diminishing returns would typically set in for more quickly for the sponsor than for the researcher. This translates into strict concavity. Second, we would like to express the feature that the sponsor is solely interested in a specific research outcome. These first two features reflect the fact that corporate sponsors tend to not only favor a more applied research agenda, but also one that is geared towards the sponsor's very specific needs. As these needs are (close to) being met completely, the sponsor may lose interest in working with the researcher. In contrast, the possibilities for expanding fundamental research are practically endless. Third, we want to explore the possibility that the sponsor's value function is enhanced under the sponsor's research agenda. Such an enhancement of the value function can take a variety of forms. Here, we are specifically interested in an "increased-focus" or "bang-for-your-buck" effect which gives the sponsor equal value at a lower investment.

Now the sponsor's value function is assumed to depend not only on I, but also on the researcher's strategy E. Let us assume that this function is strictly concave. A parsimonious way of modeling this is to assume a quadratic function: $V_s(I,R) = \sigma I - (\chi/2)I^2$, where $\sigma > 0$ and $\chi > 0$.

This functional form has the advantage that the degree of concavity is expressed by a single parameter, χ. However, the quadratic value function possesses the undesirable property of being downward-sloping beyond its maximum. This would be a distinctly unnatural element in our model. Now recall our second feature: That the sponsor is solely interested in a specific research outcome. This feature can be reflected through the assumption that the function does not decrease but remains constant at its maximum, if investment is increased further. Our third desired feature is some kind of "bang-for-your-buck" assumption. Such an effect can be captured through a single parameter $\alpha > 1$ which makes an investment $I = \widetilde{I}$ combined with research strategy S result in the same value $\widetilde{V_s}$ as an investment $I = \alpha\widetilde{I}$ combined with research strategy R. This assumption can be formulated for any functional form of $V_s(I,R)$ as $V_s(I,S) = V_s(\alpha I, R)$. Thus our three assumptions imply the following value functions for the sponsor:

$$V_s(I,R) = \left\{ \begin{array}{cc} \sigma I - (\chi/2)I^2 & \text{for} \quad I < \sigma/\chi \\ \sigma^2/2\chi & \text{for} \quad I \geq \sigma/\chi \end{array} \right\}$$

$$V_s(I,S) = \left\{ \begin{array}{cc} \alpha\sigma I - (\alpha^2\chi/2)\, I^2 & \text{for} \quad I < \sigma/\alpha\chi \\ \sigma^2/2\chi & \text{for} \quad I \geq \sigma/\alpha\chi \end{array} \right\}$$

The researcher's value function is assumed to be the same as in the previous section. For this reason, the incentive contract is still given by equations (8) and (9). To obtain a complete parametric solution, we assume that the cost function is also quadratic (although this is not necessary for any of our propositions):

$$C(I) = (\gamma/2)\, I^2$$

Under the revised assumptions, we solve for social welfare (which we still assume to be given by $W = p_s(E)V_s + p_r(E)V_r - C(I)$), the research quality index I and the players' payoffs. As before, the solutions of the incentive-contracting case are obtained by plugging the expression for the incentive contract from (8) and (9) into the sponsor's objective function.

Let $I_*^*(E)$ and $W_*^*(E)$ denote the socially optimal research environment index and the resultant welfare, conditional on research strategy E, and EU_S and EU_R the expected payoffs of sponsor and researcher. The relevant solutions are

$$I_*^*(R) = \left\{ \begin{array}{cc} \frac{P_s(R)\sigma + P_r(R)\rho}{P_s(R)\chi + \gamma} & \text{for} \quad [P_r(R)\rho\chi/\sigma\gamma] < 1 \\ \frac{P_r(R)\rho}{\gamma} & \text{for} \quad [P_r(R)\rho\chi/\sigma\gamma] \geq 1 \end{array} \right\}$$

$$W_*^*(R) = \left\{ \begin{array}{cc} \frac{[P_s(R)\sigma + P_r(R)\rho]^2}{2[P_s(R)\chi + \gamma]} & \text{for} \quad [P_r(R)\rho\chi/\sigma\gamma] < 1 \\ \frac{P_s(R)\sigma^2}{2\chi} + \frac{[P_r(R)\rho]^2}{2\gamma} & \text{for} \quad [P_r(R)\rho\chi/\sigma\gamma] \geq 1 \end{array} \right\}$$

$$I_*^*(S) = \left\{ \begin{array}{cc} \frac{P_s(S)\alpha\sigma + P_r(S)\rho}{P_s(S)\alpha^2\chi + \gamma} & \text{for} \quad [P_r(S)\alpha\rho\chi/\sigma\gamma] < 1 \\ \frac{P_r(S)\rho}{\gamma} & \text{for} \quad [P_r(S)\alpha\rho\chi/\sigma\gamma] \geq 1 \end{array} \right\}$$

$$W_*^*(S) = \left\{ \begin{array}{cc} \frac{[P_s(S)\alpha\sigma + P_r(S)\rho]^2}{2[P_s(S)\alpha^2\chi + \gamma]} & \text{for} \quad [P_r(S)\alpha\rho\chi/\sigma\gamma] < 1 \\ \frac{P_s(S)\sigma^2}{2\chi} + \frac{[P_r(S)\rho]^2}{2\gamma} & \text{for} \quad [P_r(S)\alpha\rho\chi/\sigma\gamma] \geq 1 \end{array} \right\}$$

$$I_B^* = \frac{P_s(R)\sigma}{P_s(R)\chi + \gamma};\; EU_S(I_B^*) = \frac{[P_s(R)\sigma]^2}{2[P_s(R)\chi + \gamma]};\; EU_R(I_B^*) = P_r(R)\rho I_B^*$$

$$\begin{aligned} I_C^* &= \frac{P_s(S)\left[\alpha\sigma - \frac{P_r(R)-P_r(S)}{P_s(S)-P_s(R)}\rho\right]}{P_s(S)\alpha^2\chi + \gamma}; \\ EU_S(I_C^*) &= \frac{\left\{P_s(S)\left[\alpha\sigma - \frac{P_r(R)-P_r(S)}{P_s(S)-P_s(R)}\rho\right]\right\}^2}{2[P_s(S)\alpha^2\chi + \gamma]}; \\ EU_R(I_C^*) &= \left[P_r(S) + \frac{P_r(R)-P_r(S)}{P_s(S)-P_s(R)}P_s(S)\right]\rho I_C^* \end{aligned}$$

The solutions for $I_*^*(E)$ and $W_*^*(E)$ have different expressions before and after the sponsor's value function reaches its maximum. These solutions are nevertheless continuous functions. The solutions for the benchmark and contract cases only have one expression each because the sponsor's optimal I will always occur before his value function reaches its maximum. This is because at the value function's maximum, marginal value is zero while marginal cost is positive.

Based on these solutions, a series of propositions can be derived. First, we consider what happens when $\alpha = 1$. Then, we'll allow for $\alpha > 1$.

Proposition 4 *Assume $\alpha = 1$. If a research strategy R is socially optimal the sponsor may nevertheless induce S with an incentive contract.*

Proof. We need to show that there exist parameter values such that $W_*^*(R) > W_*^*(S)$ while $EU_S(I_C^*) > EU_S(I_B^*)$. Find parameter values with a small enough difference $P_r(R) - P_r(S)$ such that $EU_S(I_C^*) > EU_S(I_B^*)$ holds. For this value of the difference $P_r(R) - P_r(S)$, the difference of squares $P_r(R)^2 - P_r(S)^2$ is also a given strictly positive number. Now let γ approach zero. This implies that the second expression in the welfare expressions becomes the only relevant one. As γ goes to zero, the term $\frac{\left[P_r(R)^2 - P_r(S)^2\right]\rho^2}{2\gamma}$ will explode and will thus be the dominant term in the comparison $W_*^*(R) - W_*^*(S)$, which will therefore be positive. Thus there exist positive values of $P_r(R) - P_r(S)$ and γ such that both $W_*^*(R) > W_*^*(S)$ and $EU_S(I_C^*) > EU_S(I_B^*)$. ■

This result shows that under the altered assumptions Proposition 1 no longer holds. The sponsor may now choose to induce strategy S even though R is socially optimal. This occurs because of the diminishing returns in the sponsor's value function. The sponsor does not take into account that the researcher's value function features constant returns. For this reason, the sponsor's underinvestment relative to the social optimum may be exacerbated by the introduction of the ex-post incentive instrument.

Proposition 5 *Assume $\alpha = 1$. The researcher can be made worse off by the introduction of incentive contracts.*

Proof. We need to show that there exist parameter values such that $EU_R(I_C^*) < EU_R(I_B^*)$ while $EU_S(I_C^*) > EU_S(I_B^*)$. We can set ρ such that $\sigma - \frac{P_r(R) - P_r(S)}{P_s(S) - P_s(R)}\rho$ is arbitrarily close to zero. Thus we can set both I_C^* and $EU_S(I_C^*)$ arbitrarily close to zero. Now, reduce both $P_s(S)$ and $P_s(R)$ so that the difference $P_s(S) - P_s(R)$ remains constant but $P_s(R)$ goes to zero. By doing this, we can reduce $EU_S(I_B^*)$ to a number even smaller than $EU_S(I_C^*)$, no matter how small we have already made $EU_S(I_C^*)$. As $P_s(R)$ goes to zero, I_B^* converges to a positive number $1/\gamma$, and therefore $EU_R(I_B^*)$ converges to some positive number. As we could have initially set I_C^* , and therefore $EU_R(I_C^*)$, arbitrarily close to zero, we can guarantee that $EU_R(I_C^*) < EU_R(I_B^*)$ while $EU_S(I_C^*) > EU_S(I_B^*)$. ■

In contrast to the first section's model, this section's assumptions allow for the possibility that the researcher is being made worse off by the introduction of incentive contracts. This result, like the previous one, is accounted for by the discrepancy between the sponsor's value function and the researcher's value function, with the former exhibiting diminishing returns while the latter has constant returns. The proof indicates under which conditions the perverse result will occur. With a high level of ρ, the researcher must receive a high transfer per each invested dollar. This, combined with the diminishing returns, prompts the sponsor to offer only a very low level of investment in the contract case. In the benchmark case, the sponsor would offer a higher level of investment, which however yields a lower overall payoff than the contract case because of the combination of diminishing returns and the very low probality of research success $P_s(R)$.

Let us now allow for $\alpha > 1$. The presence of a bang-for-your-buck effect will make it more attractive for the sponsor to induce a contract:

Proposition 6 *As α increases, the set of parameter values for which the sponsor prefers to offer a contract expands unambigiously.*

Proof. An increase in α allows the sponsor to achieve equal $V_s(I,S)$ at lower I, but leaves both $V_S(I,R)$ and t_s unchanged. ■

It is not clear whether investment under a contract will be increased as a result of the bang-for-your-buck effect:

Proposition 7 *As a result of $\alpha > 1$, compared to the case $\alpha = 1$, I_C^* may be increased or reduced. For values of χ close enough to zero, I_C^* will be increased, while for values of χ that are high enough (i.e., above a threshold value), I_C^* will be reduced.*

Proof. For a given $\alpha > 1$, as χ goes to zero, so does the term $P_s(S)\,\alpha^2\chi$, which is part of the denominator of I_C^* . The effect of having α in the numerator will thus dominate the effect of having α in the denominator. The reverse is true for a sufficiently large χ. ■

Corollary 8 *For sufficiently low χ, as a result of $\alpha > 1$, compared to the case $\alpha = 1$, the likelihood of the researcher being made worse off as a result of the introduction of contracts is being reduced. With sufficiently high χ, as* *a result of $\alpha > 1$, compared to the case $\alpha = 1$, the likelihood of the researcher being made worse off as a result of the introduction of contracts is being increased.*

Proof. Follows from the preceding two propositions. The likelihood of the researcher being made worse off depends on the range of parameter values for which this is the case. By proposition 6, the presence of $\alpha > 1$ increases the set of parameter values for which the sponsor prefers to use a contract. And, by proposition 7, for sufficiently low χ, the presence of $\alpha > 1$ benefits the researcher in case a contract is chosen, due to a higher I_C^* - as indicated by the expression for $EU_R\left(I_C^*\right)$ .Conversely, for sufficiently high χ, the presence of $\alpha > 1$ harms the researcher in case a contract is chosen, due to a lower I_C^*. ■

The bang-for-your-buck effect thus makes the researcher more likely to benefit from the introduction of incentive contracts if the sponsor's value function is only slightly concave, while it makes the researcher more likely to be harmed by the introduction of incentive contracts if the sponsor's value function is strongly concave. In case of a linear value function for the sponsor as in section 1, the researcher will benefit from the bang-for-your-buck effect. In this case, the increased productivity of investment makes it only more attractive for the sponsor to offer a contract combined with a high level of investment. However, in case of strongly diminishing returns for the sponsor, the bang-for-your-buck effect implies that the sponsor can achieve the same results at a lower cost due to a reduced investment by inducing $E = S$. The bang-for-your-buck effect means that the diminishing returns occur sooner, i.e. already at a low level of I.

4 Bargaining Power

We have seen in the previous section that a researcher can be made worse off by the introduction of incentive contracts for specific value functions. This result crucially depends on the timing described in section 2.1. Implicitely the timing gives all the bargaining power to the sponsor. This is reflected by the sponsor making a take it or leave it offer to the researcher. In reality a sponsor has all the bargaining power whenever there are many researchers that could potentially conduct the research project. In the case where the research project is very specific and can only be conducted by a certain researcher with abilities specific to the project the researcher would have all the bargaining power. For such a situation our timing assumption is not appropriate. To see this imagine the researcher knows that the he is the only person that can possibly conduct the reasearch project in question. Then the researcher may decline a contract offer which is not favourable for him, knowing that the sponsor will come back an renegotiate. The sponsor will do so if the research project generates an expected surplus. In the case where the sponsor has all the bargaining power this surplus will entirely go to the sponsor.

An alternative setting for a non-replaceable researcher would be the researcher proposing a contract. As the firm is assumed to be risk-neutral and limited liability does not apply, the reserach contract would maximize the expected return for the researcher subject to the constraint that the expected return for the firm is zero. Then the whole expected surplus would be absorbed by the researcher. Such a contract could include an investment and a fixed wage payment for the researcher. If incentive contract are feasible an additional bonus for a project that leads to a success for the sponsor would be part of the contract. However, in such a framework the feasibility of an incentive contract can never make the researcher worse off as he would just not propose a contract containg an incentive component if it would lead to an inferitor outcome.

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