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MODELLING AGRICULTURAL PUBLIC R&D COFINANCING WITHIN A PRINCIPAL-AGENT FRAMEWORK

The case of an Italian region

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Abstract [(*)]

This paper analyses how a public institution chooses the optimal contract (cofinancing rate) in funding agricultural R&D research projects. A theoretical model is developed within a principal-agent framework taking into account the asymmetric information both players have to handle. The researcher (the agent) initially does not know the cofinancing granted by the funding institution (the principal). This latter, in turn, only observes some objective features of the researchers and of the selected research projects and, ex post, the research outcome, but not the agent's actual effort on the project. The principal uses the available information to offer the cofinancing rate (the contract) that, under specific contractual clauses, induces the agent's effort that maximizes principal's utility. The model eventually assumes the form of a Stackelberg-type game. An empirically testable relation is also derived from the theoretical model and is then applied to the agricultural R&D programme funded by the Italian region Emilia-Romagna over years 2001-2006.

Key-words: Public R&D Funding, Principal-Agent Problem, Stackelberg-type game, Censored-Normal Regression.

JEL Classification: Q160, O320

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1. Introduction

In the last decades, the scientific debate on agricultural R&D public funding progressively shifted the attention from the optimal amount of expenditure to its optimal allocation, i.e., how optimally allocate the fixed or even diminishing amount of resources (Huffman and Just, 1994, 1999a, 1999b; Huffman et al., 2006; Pardey and Beintema, 2002; Pardey *et al*., 2006; Spielman and von Grebmer, 2004). This latter aspect emphasizes a key issue of public research funding: it always involves two players whose interests and objectives tend to diverge (Huffman and Just, 2000). On the one hand, the funding public institution aims at obtaining the maximum outcome (*payoff*) from the funded research activities in terms of social net benefits. On the other hand, the researcher aims at raising funds and progressing in his professional (academic) career. This potential clash of interests becomes an issue for the presence of asymmetric information between the two players (Materia and Esposti, 2009). Public research funding thus takes the form of a contract between such players under this asymmetry.

At many different levels (regional, national, European) one funding mechanism has progressively emerged. It consists in granting public funds to research projects selected within a competitive procedure and through a cofinancing agreement. We may wonder why and when this funding mechanism approach is expected to be rational. We may regard this approach as a two-stage process: the funding institution firstly run a competition and select among projects presented by the researchers. Then, it proposes them the contract, namely, the cofinancing rate granted to the project. From the perspective of the funding institution the problem then becomes how to optimally define the cofinancing rate in this kind of contract and, in particular, which characteristics of projects and researchers have to affect this optimal cofinancing rate. This paper aims at modelling this funding mechanism. Within a principal-agent framework, the public funding institution (the principal) looks for the optimal compromise between two conflicting aspects. On the one hand, the need of an high-enough cofinancing rate to induce the researcher (the agent) to spend his effort within the project. On the other hand, alternative uses of public expenditure encourage the principal to maintain the cofinancing rate at the lowest possible level.

Though issues related to the appropriate design of R&D public funding and to this specific funding mechanism are not evidently exclusive of agricultural R&D (David, 2000), a model is here developed with specific reference to the agricultural case. Not only for the sectoral empirical application presented hereafter; also because the large prevalence of public funding in agricultural R&D (Huffman and Just, 1999b)[1] and the increasing use of cofinancing research contracts (Materia, 2008) make the sector particularly suitable for the present analysis.

On the basis of specific assumptions about agent's behaviour and principal's expectations, section 2 develops the model deriving the behaviour of the funding institution (i.e., the optimal cofinancing rate) and analysing how it is affected by observable characteristics of the researchers and of the research projects. To achieve this, section 3 firstly presents comparative static analysis and then performs numerical simulations. An empirically tractable and estimable relationship between the cofinancing rate and these observable variables is derived in section 4. To finally assess the consistency of model predictions with real data, this empirical relation is estimated in section 5. The application concerns public agro-food R&D funding carried out by Regione Emilia-Romagna (one of the largest Italian administrative region) over the period 2001-2006. Section 6 concludes.

2. The model

2.1. The logic and the assumptions

Let us consider the two players involved in research funding: the public funding institution (the principal) and one (or many) researcher(s) that carries out the research work (the agent). Assume a funding mechanism where R&D projects are selected after a competitive proposal evaluation process and then funded through a cofinancing agreement. It is helpful to represent this funding mechanism as a two-stage process (Figure 1). Initially, researchers submit projects and compete for funding. Then, once the public institution has selected some projects exclusively on the basis of the scientific-technical merit (peer-reviewing), the principal offers a contract (namely, a cofinancing rate) to the agents.

From the principal's perspective, the selection stage does not only pursue the best allocation of a limited budget through the objective and competent evaluation of peer-reviewers. The first stage also aims at collecting information on competing researchers

[1] This is definitely the case in Italy. Alfranca and Huffman (2003) show that private expenditure, in the nineties, amounted to about 25% of total agricultural R&D in Italy. Among other EU countries it was about 60% in the UK and only 10% in Germany and Spain.

(agents). They have to disclose information about themselves and their research activities to participate in the competition and maximize their chances to succeed. This additional information can be then used by the principal in the following contracting stage.

The peculiar characteristics of research activities are riskiness (the outcome is uncertain in timing, quantity and quality of results) and presence of asymmetric information. On the former aspect, for the sake of simplicity, both players are here assumed risk neutral[2]. Asymmetric information occurs because the principal can not observe the actual effort (for instance, days of work) the i-th agent is going to spend on the project (e_i)[3], while, on the contrary, the agent can not know, when he prepares and submits the project, the cofinancing rate the principal will offer (μ_i) after project approval.

At the same time, however, the principal has two major sources of information about projects and agents. On the one hand, he observes, *in-itinere* or *ex-post*, the outcome of the research projects (R_i). On the other hand, he receives from the peer-reviewers an objective and competent evaluation informing him about real agent's ability (θ_i) and declared project's cost (C_i). On this basis, if the principal is able to deduce the researcher's "production function" from the contents of the project proposal, he can thus infer the agent's effort on the project (e_i), *ex-post*, by observing research results.

The first modeling step concerns players' behaviour. We assume that both players aim at maximizing their utility. The researcher looks for the optimal allocation of his efforts and own funds to maximize his research results. The public funding institution looks for the cofinancing rate that maximizes the overall social benefits from public funds. Let us firstly define the respective utility functions. After project approval, the i-th agent utility function can be measured in terms of research results as follows:

$$(1) \qquad U_i^A = R_{1i}^A + R_{2i}^A = \left(\theta_i^d e_i^b C_{1i}^a\right) + \gamma\left\{\theta_i\left(E_i - e_i\right)\left[W_i + \mu_i C_i - C_{1i}\right]\right\} \ , \quad \forall i = 1,\dots N$$

where E and W are the overall effort (in terms of working time) and financial endowments of the agent, respectively. C_{1i} are the financial resources actually spent in the research project. $0 \le \mu_i \le 1$ is the cofinancing rate and $\left(\mu_i C_i\right)$ is the amount of funds granted by the principal on the basis of the declared cost the research project, C_i. In (1) the agent allocates the total

[2] In Huffman and Just (2000), for instance, the principal is risk neutral while the agent is risk adverse.
[3] Henceforth, index *i* identifies both the generic project and the generic researcher among the N selected projects (researchers), the assumption being that they coincide (namely, that any researcher submits only one successful project).

financial resources, $\left(W_i + \mu_i\, C_i\right)$ and the total effort (*E*) between the project and alternative research activities. The financial resources spent in alternative research thus are $C_{2i} = \left[W_i + \mu_i\, C_i - C_{1i}\right]$. $R_{1i}^A = \left(\theta_i^d e_i^b C_{1i}^a\right)$ is the expected outcome of the research project (in terms of publications, patents, etc.) and $R_{2i}^A = \gamma\left\{\theta_i \left(E_i - e_i\right)\left[W_i + \mu_i\, C_i - C_{1i}\right]\right\}$ is the expected output of alternative research activities for which, however, no public cofinancing is provided.[4] $d, b, a, \gamma > 0$ are fixed (i.e., invariant across research projects or agents) unknown parameters expressing returns to ability, effort and financial resources.

These two research production functions are evidently different. Both assume a Cobb-Douglas form but R_{1i}^A shows variable marginal returns to ability, effort and financial resources, while R_{2i}^A is a sort of linear production function as it shows constant marginal returns to all research production factors (provided that the amount of the other factors remains constant). The economic argument underlying this different functional specification is that the i-th research project is a single activity for which it is reasonable to admit decreasing returns to ability, effort and financial resources (i.e, $0 < d, b, a < 1$). On the contrary, there is no reason to impose decreasing returns over the possibly large and unbounded set of alternative research activities[5]. There is also a practical argument supporting these functional specifications. They make the first and second order derivatives of the objective function (and, therefore, the associated maximization problem) analytically treatable.

Now, let us consider the principal's utility function associated to the i-th selected project and expressed in terms of the resulting social benefits from research outcomes:

$$(2) \qquad U_i^P = R_{1i}^P - R_{2i}^P = \left[\varphi\left(\theta_i^d e_i^b C_i^a\right) - \mu_i C_i\right] - \left(\mu_i C_i\right)^\rho$$

where utility $R_{1i}^P = \left[\varphi\left(\theta_i^d e_i^b C_i^a\right) - \mu_i C_i\right]$ expresses the i-th project expected outcome in terms of social benefits net of the public funds allocated to the project itself, $\left(\mu_i C_i\right)$. Parameter $\varphi > 0$, therefore, converts the research output into social benefits. The reservation utility

[4] As both players are risk neutral, it follows that agent's and principal's utilities are only affected by the expected outcome of the research activity, while other aspects of its stochastic nature (variance and covariance) do not matter.
[5] Among these possible alternative activities we should also include the i-th project itself when not submitted to the competitive selection process and, thus, entirely funded by the agent.

$R_{2i}^{P} = (\mu_i C_i)^{\rho}$ expresses the net social benefits obtainable from alternative uses[6] of public funds $(\mu_i C_i)$. $\rho > 0$ is the net return parameter of these alternative uses.

The clash of objectives between the two players, given the asymmetric information, makes this research funding mechanism assume the typical features of a contract-design problem in a principal-agent framework (Huffman and Just, 2000). In this case, the object of the contract is the cofinancing rate (between 0 and 1) granted by the principal.

2.2. The nature of the research contract

(2) makes explicit that the principal purposes the highest possible e_i ($\partial U_i^P / \partial e_i > 0$) while minimizing the cofinancing rate μ_i ($\partial U_i^P / \partial \mu_i < 0$). The principal, however, can not decide the level of e_i. He can only decide μ_i that, in turn, affect agents' effort. The agent decides how much effort to spend on the project once the project has been selected and the contract (μ_i) offered by the principal. Therefore, the principal aims at using the cofinancing rate μ_i to induce the maximum agent's effort on the project.

Moral hazard can evidently occur typically in the form of a post-contractual opportunistic behaviour of the agent: with respect to the project's original contents, the agent can change the allocation of both effort and financial resources after he accepts the cofinancing rate offered by the principal. The principal only partially admits this moral hazard behaviour. On the one hand, he has to accept the possibility that the agent, once his own project has been selected and cofinanced, decides to reallocate part of the effort in alternative research activities. On the other hand, however, the principal excludes that the agent uses part of the funds granted by the principal to carry out alternative R&D activities.

This principal's belief about agent's moral hazard behaviour is grounded on the design of the contract he offers to the agent. Together with the granted μ_i, the contract includes three clauses. The first is the *compatibility clause* and establishes that the agent is allowed to run other research activities in parallel with the funded project. The second is the *recession clause* and admits that the agent, though selected in the first stage, can decide to reject the cofinancing rate offered by the principal thus not participating to the contract. As will be shown in the following sections, these two clauses are needed because otherwise the agents

[6] For instance, investments in public infrastructure.

would not even participate to the first stage (the selection process). The third is the *sanction clause* and establishes that, as soon as the principal observes a research outcome that is an appreciable deviation from expected behaviour, i.e., from the full use of granted funds within the project[7], he can immediately sanction the agent by receding from the contract (thus stopping funding) if he is able to evaluate project results *in-itinere*, or he can sanction the agent *ex-post*, for instance not paying the finance balance of the project, excluding him from future funding or, more simply, just in terms of loss of reputation. The application of this clause is credible in agent's perspective because, according to the assumptions made above, he knows that his "production function" can be observed (through project contents), namely, that the principal knows the expected project results, given the cofinancing rate, the ability, the project cost and the expected effort.

2.3. Agent's Optimization

Given the nature of the contract, the principal may optimally design it by firstly inferring agent's optimizing behavioural rule. The *i-th* selected agent (project/researcher) maximizes his own utility function with respect to the behavioural variable e_i under the three contractual clauses:

$$(3) \qquad \max_{e_i} U_i^A = \left(\theta_i^d e_i^b C_i^a\right) + \gamma \left\{\theta_i \left(E_i - e_i\right)\left[W_i + \mu_i C_i - C_i\right]\right\}$$

The agent looks for that level e_i^* that represents the best allocation (in terms of research results) of his total effort *E* across all possible research activities. Given the third contractual clause, however, he restricts himself from using the principal's grants, $\mu_i C_i$, outside the funded research project. Consequently, C_i in (3) corresponds to C_{1i} in (1).

Imposing the first-order condition on (3) we obtain:

[7] It must be acknowledged that the principal only knows the "stochastic production function" of the researcher/project, namely, the expected research output. What the principal observes *ex post*, in fact, is the actual research output. Therefore, in principle, the difference between the actual and the expected output can be attributed either to the stochastic nature of the R&D activity or to the moral hazard of the researcher. Therefore, the assumption is made that the principal is able to distinguish, *ex post*, between a poor research result due to moral hazard and a randomly generated poor research result. In practice, however, what we are really assuming is that the agent does not want to take the risk of a forbidden (according to the contract) moral hazard behaviour because he is convinced that the funding institution might associate a poor research result to his moral hazard then imposing him the consequent sanctions.

(4) $$\frac{\partial U_i^A}{\partial e_i} = 0 \Rightarrow b\theta_i^d e_i^{b-1} C_i^a - \gamma\theta_i \left[W_i + \mu_i C_i - C_i\right] = 0$$

from which we can derive the agent's optimal effort (e_i^*):

(5) $$e_i^* = \left[\frac{\gamma}{b}\theta_i^{1-d} C_i^{-a}\left(W_i + \mu_i C_i - C_i\right)\right]^{\frac{1}{b-1}}$$

The second order condition clearly indicates that (5) is always a maximum, provided that $0 < b < 1$[8]:

(6) $$\frac{\partial^2 U_i^A}{\partial e_i^2} < 0 \Rightarrow (b-1)\, b\, \theta_i^d\, e_i^{b-2} C_i^a < 0$$

The optimal effort thus depends on the invariant return parameters d, b, a, γ, but also on θ_i, C_i and, in particular, μ_i offered by the principal. Agent's optimal effort varies with respect to these variables as follows:

(7) $$\frac{\partial e_i^*}{\partial \mu_i} = \frac{1}{b-1}\left(\frac{\gamma}{b}\theta_i^{1-d} C_i^{1-a}\right)\left\{\frac{\gamma}{b}\theta_i^{1-d} C_i^{-a}\left[W_i + \mu_i C_i - C_i\right]\right\}^{\frac{2-b}{b-1}}$$

(8) $$\frac{\partial e_i^*}{\partial \theta_i} = \frac{1}{b-1}(1-d)\left\{\frac{\gamma}{b}\theta_i^{2-b-d} C_i^{-a}\left[W_i + \mu_i C_i - C_i\right]\right\}^{\frac{1}{b-1}}$$

(9) $$\frac{\partial e_i^*}{\partial C_i} = \frac{1}{b-1}\frac{\gamma}{b}\theta_i^{1-d}\left\{\frac{\gamma}{b}\theta_i^{1-d} C_i^{-a}\left[W_i + \mu_i C_i - C_i\right]\right\}^{\frac{2-b}{b-1}}\left[(1-a)(\mu_i - 1)C_i^{-a} - aW_i C_i^{-(1+a)}\right]$$

Provided that $0 < b < 1$, (7) demonstrates that the optimal agent's effort always declines with the increase of μ_i. It is worth noticing that, by definition of *W*, it must be $W_i \geq (1-\mu_i)C_i$, otherwise the agent could not provide its part of funding on the project. Therefore, it is always $W_i + C_i(\mu_i - 1) \geq 0$. For this reason, (9) shows that the optimal agent's effort always increase with the increase of C_i. Evidently, an higher cost generates an higher productivity of the effort within the project and, at the same time, subtracts financial resources to alternative research activities.

[8] By definition, it is $\theta, e, C > 0$.

On the contrary, according to (8), the response of agent's optimal effort to a change in his ability, θ_i, may be either positive or negative. This different behaviour can be explained by the fact that, unlike effort and financial resources, ability is not rival across research activities. Therefore, the sign of the response of e_i^* only depends on the returns of θ_i within the project. When $0 < d < 1$ (therefore under decreasing marginal returns to θ_i) the effort will always decrease with the increase of θ_i. Under increasing marginal returns to θ_i $(d > 1)$, the response of the effort to ability will become positive. The economic rationale is straightforward: whenever the returns to ability are higher (lower) in the project rather than in alternative activities it is convenient for the agent to reallocate his effort in favour of the project (of the alternative activities) itself.

2.4. Principal's Optimization

On the basis of the abovementioned nature of the contract and of his beliefs, the principal takes agent's behaviour as given, thus includes the optimal effort (e_i^*) in utility function (2) to decide about his own behavioural variable, μ_i:

(10a) $$\max_{\mu_i}\left\{\left[\varphi\theta_i^d e_i^{*b} C_i^a - \mu_i C_i\right] - \left(\mu_i C_i\right)^\rho\right\}$$

By substituting (5) in (10a), we obtain:

(10b) $$\max_{\mu_i}\left\{\varphi\theta_i^d\left[\frac{\gamma}{b}\theta_i^{1-d}C_i^{-a}\left(W_i + C_i\left(\mu_i - 1\right)\right)\right]^{\frac{b}{b-1}} C_i^a - \mu_i C_i - \left(\mu_i C_i\right)^\rho\right\}$$

The respective first-order condition is:

(11) $$\frac{\partial U_i^P}{\partial \mu_i} = 0 \Rightarrow \frac{\gamma}{b-1}\varphi\theta_i\left[\frac{\gamma}{b}\theta_i^{1-d}C_i^{-a}\left(W_i + C_i\left(\mu_i^* - 1\right)\right)\right]^{\frac{1}{b-1}} - \rho C_i^{\rho-1}\left(\mu_i^*\right)^{\rho-1} - 1 = 0$$

where μ_i^* indicates the optimal cofinancing rate provided that the second order condition holds true:

(12)

$$\frac{\partial^2 U_i^P}{\partial \mu_i^2} < 0 \Rightarrow \frac{\gamma^2}{b(b-1)^2}\varphi\theta_i^{2-d}C_i^{1-a}\left[\frac{\gamma}{b}\theta_i^{1-d}C_i^{-a}\left(W_i + C_i\left(\mu_i^* - 1\right)\right)\right]^{\frac{2-b}{b-1}} < \rho(\rho-1)C_i^{\rho-1}\left(\mu_i^*\right)^{\rho-2}$$

As $0 \le \mu_i \le 1$, clear conclusions can be drawn from (11) and (12). For $0 < b < 1$ and all parameters >0, in fact, (12) may hold true only for negative values of μ_i and the first-order condition can never be met for $0 \le \mu_i \le 1$. After all, from direct inspection of (10b), it is already evident that, for non-negative value μ_i, the maximum principal's utility is always reached when $\mu_i = 0$. The economic argument is immediate: with $\mu_i = 0$ the agent's effort will be maximum while the principal's explicit and implicit (opportunity) costs ($\mu_i C_i$ and $(\mu_i C_i)^\rho$, respectively) will be minimum. Evidently, however, no agent is willing to accept such contract. Namely, all agents would make use of the second contractual clause and recede. If this clause was not admitted in the contract, the agent would not even participate to the selection procedure. Therefore, if we assume that, for symmetry, the agents are perfectly able to foresee this principal's behaviour, the implication of this behaviour would be that no agent will even enter the first stage of the process.

As a consequence, to avoid a generalized recession from the contract or self-exclusion from the selection process by the agents, the principal's behavioural rule can not be expressed by (11). He must rather take into account the participation constraint of the agent. The agent utility from participating to the selection process and, then, accept the contract must be at least equal to the utility the agent can obtain by spending all his own efforts and financial resources in alternative research activities (i.e., his reservation utility). Such agent's participation constraint is:

$$(14) \qquad \left(\theta_i^d e_i^b C_i^a\right) + \gamma\left[\theta_i (E_i - e_i)\left(W_i + \mu_i C_i - C_i\right)\right] \ge \gamma\left(\theta_i E_i W_i\right)$$

where $\gamma(\theta_i E_i W_i)$ is the agent's reservation utility. If (14) is not met, namely, whenever the reservation utility is larger than U_i^A, the agent is expected to recede from the contract (by rejecting the principal's offer μ_i). In such case, e_i will be 0.

Given this participation constraint, the principal's problem has to be rewritten as follows:

$$(10c) \qquad \max_{\mu_i} \left\{\left[\varphi \theta_i^d e_i^b C_i^a - \mu_i C_i\right] - (\mu_i C_i)^\rho\right\}$$

s.t.:

$$\left(\theta_i^d e_i^b C_i^a\right) \ge \gamma\left(\theta_i E_i W_i\right) - \gamma\left[\theta_i (E_i - e_i)\left(W_i + \mu_i C_i - C_i\right)\right]$$

$$\left(\theta_i^d e_i^b C_i^a\right) \geq \frac{\mu_i C_i + (\mu_i C_i)^\rho}{\varphi}$$

The second constraint represents the principal's constraint that completes his contractual behaviour: the principal will never offer a cofinancing rate that makes the social benefits generated by the granted project lower than benefits that would be generated by using the same public funds in alternative investments. The two constraints in (10c) evidently are mutually exclusive: if the former is binding the latter is slack (and *vice versa*). In particular, if the latter is more binding the funding programme will not even exist; it happens when the maximum μ_i the principal is willing to propose (corresponding to the value at which the net utility U_N, i.e., utility from the project less the reservation utility, equals 0) is lower than the minimum μ_i the agent is willing to accept. Figure 2 illustrates how the two participation constraints may combine in generating a non-empty set of possible contractual outcomes μ_i^*: for the funding programme to start, there must exist a set of values of μ_i for which the participation constraint of both players is respected. Still, if existent, the optimal μ_i^* is always decided by the agent's participation constraint. Therefore, we can solve (10c) skipping the second constraint.

(10c) can be solved by applying the Kuhn-Tucker Theorem. The Lagrangian function is:

(15)

$$L = \left\{\left[\varphi \theta_i^d e_i^b C_i^a - \mu_i C_i\right] - (\mu_i C_i)^\rho\right\} - \lambda\left\{\gamma(\theta_i E_i W_i) - \left[\left(\theta_i^d e_i^b C_i^a\right) + \gamma\theta_i\left(E_i - e_i\right)\left(W_i + \mu_i C_i - C_i\right)\right]\right\}$$

where λ is the Kuhn-Tucker multiplier. According to the Kuhn-Tucker sufficiency, solutions to (15) satisfy the following conditions:

$$(16)\quad \begin{cases} \dfrac{\partial L}{\partial \mu_i} = 0 \\ \lambda \geq 0 \text{ when } \left\{\gamma(\theta_i E_i W_i) - \left[\left(\theta_i^d e_i^b C_i^a\right) + \gamma\theta_i (E_i - e_i)\left(W_i + \mu_i C_i - C_i\right)\right]\right\} = 0 \\ \lambda = 0 \text{ when } \left\{\gamma(\theta_i E_i W_i) - \left[\left(\theta_i^d e_i^b C_i^a\right) + \gamma\theta_i (E_i - e_i)\left(W_i + \mu_i C_i - C_i\right)\right]\right\} < 0 \end{cases}$$

The former equation is the usual first-order condition of the Lagrangian function while the latter equations are the so-called complementary slackness conditions. If the constraint is slack (not binding, i.e. $\lambda = 0$), once e_i in (15) is substituted with (5), the problem will correspond to (10b) and it will be $\mu_i^* = 0$. But this solution clearly violates the agent's participation constraint unless the returns to ability, effort and own financial resources in the project are higher than in alternative activities for any level of θ_i, e_i and C_i. This circumstance, however, is excluded for e_i as we assumed $0 < b < 1$, i.e., that the objective function of the agent is concave in e_i. Moreover, in such case the agent would simply carry out the project in any case, regardless external funding.

From the Kuhn-Tucker sufficiency, as well as from direct examination of problem, and under the assumed values of model parameters, we can conclude that the only non-trivial case is a contract that satisfy (5) and for which the agent's participation constraint is always binding:

$$(17) \qquad \left(\theta_i^d e_i^{*b} C_i^a\right) + \gamma\left[\theta_i \left(E_i - e_i\right)\left(W_i + \mu_i C_i - C_i\right)\right] = \gamma\left(\theta_i E_i W_i\right)$$

Substituting (5) and after some simple algebraic manipulations to isolate μ_i^*, the boundary solution (17) can also be rewritten as:

$$(18) \qquad \mu_i^* + \frac{\left[\theta_i^{\frac{1-d}{b-1}} C_i^{\frac{1-(a+b)}{b-1}} \left(\frac{\gamma}{b}\right)^{\frac{b}{b-1}} \left(W_i + \mu_i^* C_i - C_i\right)^{\frac{b}{b-1}}\right] - \gamma E_i W_i}{\gamma C_i \left[E_i - \theta_i^{\frac{1-d}{b-1}} C_i^{-\frac{a}{b-1}} \left(\frac{\gamma}{b}\right)^{\frac{1}{b-1}} \left(W_i + \mu_i^* C_i - C_i\right)^{\frac{1}{b-1}}\right]} - \left(1 - \frac{W_i}{C_i}\right) = 0$$

(18) is the reduced-form relationship linking the optimal contract (i.e., cofinancing rate) to the characteristics of the i-th project and agent (E_i, W_i, θ_i and C_i) and to the invariant parameters $d, a, \gamma > 0$ and $0 < b < 1$. From (18) and the underlying modelling approach, we can draw three general propositions about this funding mechanism and the respective contract.

Proposition 1*: The principal's utility function is irrelevant for the optimal contract.*

As the optimal cofinancing rate in (18) only comes from agent's utility function and his participation constraint, the principal utility function (2) is apparently irrelevant. Therefore, parameters φ and ρ would not matter, too. Actually, φ and ρ enter the principal's participation constraint $\left(\theta_i^d e_i^b C_i^a\right) \geq \frac{\mu_i C_i + \left(\mu_i C_i\right)^\rho}{\varphi}$. Therefore, though they do not affect the optimal contract μ_i^*, an high-enough φ and a low-enough ρ are needed to make the contract itself exist.

Proposition 2*: The contractual clauses are strictly needed to make the funding mechanism work.*

The model makes clear that, if the *compatibility* and *recession clauses* were not included, the funding mechanism would have a trivial outcome with the principal always offering $\mu_i = 0$ and the agent never finding any interest in participating to such research contracts. In fact, without these two contractual clauses the whole funding process would not even start.

Proposition 3*: The funding mechanism works as a Stackelberg-type game.*

The model does not behave as a conventional principal-agent model (Gibbons, 1998). Although the theoretical framework assumes the typical features of a principal-agent problem (due to asymmetric information) and equation (5) still looks like an *incentive-compatibility condition* of a conventional principal-agent model, the model here developed excludes post-contractual opportunistic behaviours of the agent. Given assumptions made and the third contractual clause, the post-contractual behaviour of the agent exactly follows the principal's expectations in order to avoid sanctions (from loss of reputation to loss of money). On this basis, the principal can offer its optimal contract accordingly. The model consequently assumes the typical features of a *Stackelberg-type game* where the funding institution (the principal) acts as the *leader* that exactly knows the response function of the agent. The researcher (the agent) acts as the *follower* that behaves according to principal's expectations as he does not find any convenience in opportunistic behaviour[9].

[9] For this reason and to avoid confusion, henceforth we will always use the term "funding institution" instead of "principal" and "researcher" instead of "agent". Actually, if the researchers did not care about the possible sanctions, the model would really become a typical principal-agent model. The principal would have to propose appropriate incentives to contain the moral hazard behaviour and/or would need to spend resources in controlling and monitoring agents' behaviour. More details on principal-agent models in research contracts can be found in Holmstrom (1989) and Levitt (1995). Some further interesting developments in these modelling exercises are also suggested in Sun (2008). Model developments in this field have been recently proposed also with respect to "private-to-private" research contracts (Norbäck and Persson, 2009) or to the design of public University systems (Agasisti and Catalano, 2009).

Within this game, model (18) represents how the cofinancing rate (the optimal contract) offered by the public funding institution is expected to change whenever the characteristics of researchers and research projects (namely, E_i, W_i, θ_i and C_i) change. In particular, the interest here is on analysing how the funding institution uses the information provided within the submitted projects. As E_i and W_i are hardly observable even after project submission, the available information concerns θ_i and C_i as illustrated in the project documentation and emerged in the selection process. This information can be used by the funding institution to establish the optimal contract. On a purely empirical ground, however, the issue can be re-formulated as follows: given the observed cofinancing rates μ_i and their relationship with observed θ_i and C_i, can we empirically assess whether, and under which model parameters, model (18) is supported by real data?

3. Comparative statics and numerical simulations

3.1. Comparative statics

To give an empirical content to the funding mechanism modelled in previous section, we have to figure out how the behaviour of the two players (namely, variables e_i^* and μ_i^*) depends on either observable or unobservable characteristics of researchers and research projects. While taking derivatives with respect to these independent variables is relatively straightforward for e_i^* (see equations (7)-(9) and comments thereafter), however, such comparative statics' analysis is not immediate for μ_i^* since (18) is in implicit form. Nonetheless, (18) still expresses the functional relationship between μ_i^*, E_i, W_i, θ_i and C_i, that is, $f\left(\mu_i^*, E_i, W_i, \theta_i, C_i\right) = 0$. In particular, we are here interested in the relationship between the behavioural variable of the funding institution, μ_i^*, and the observable characteristics of projects and researchers, θ_i and C_i.

We can express these relationships with the implicit functions $f_1\left(\mu_i^*, C_i\right) = 0$ and $f_2\left(\mu_i^*, \theta_i\right) = 0$. The Implicit Function Theorem indicates under which conditions the respective explicit functions $\mu_i^* = g_1(C_i)$ and $\mu_i^* = g_2(\theta_i)$ exist. Let us assume that the two generic points (μ_0, C_0) and (μ_0, θ_0) are solutions to the implicit functions above, i.e.,

$f_1(\mu_0, C_0) = 0$ and $f_2(\mu_0, \theta_0) = 0$. We can then conclude that the explicit functions $\mu_i^* = g_1(C_i)$ and $\mu_i^* = g_2(\theta_i)$ exist in open intervals centred in (μ_0, C_0) and (μ_0, θ_0) provided that, within these intervals, $f_1(\mu_i^*, C_i)$ and $f_2(\mu_i^*, \theta_i)$ are continuously differentiable and $\frac{\partial f_1(\mu_0^*, C_0)}{\partial \mu_0^*} = \frac{\partial f_2(\mu_0^*, \theta_0)}{\partial \mu_0^*} \neq 0$. Under such conditions, functions $\mu_i^* = g_1(C_i)$ and $\mu_i^* = g_2(\theta_i)$ are, in turn, continuously differentiable and their first-order derivatives can be derived as implicit functions as follows:

(19a) $g_1'(C_i) = -\frac{f_{1C}(\mu_i^*, C_i)}{f_{1\mu}(\mu_i^*, C_i)}$

(19b) $g_2'(\theta_i) = -\frac{f_{2\theta}(\mu_i^*, \theta_i)}{f_{2\mu}(\mu_i^*, \theta_i)}$

where $f_{1C}(\mu_i^*, C_i) = \frac{\partial f_1(\mu_i^*, C_i)}{\partial C_i}$, $f_{2\theta}(\mu_i^*, \theta_i) = \frac{\partial f_2(\mu_i^*, \theta_i)}{\partial C_i}$ and $f_{1\mu}(\mu_i^*, C_i) = f_{2\mu}(\mu_i^*, \theta_i) = \frac{\partial f_1(\mu_i^*, C_i)}{\partial \mu_i^*} = \frac{\partial f_2(\mu_i^*, \theta_i)}{\partial \mu_i^*}$.

Let us consider the following intervals: $\mu_i^* \in [0,1]$, $C_i \in [1,2]$ and $\theta_i \in [0.00025, 0.01]$. As shown in numerical simulations below (Figures 6 and 7), within this interval there exist solutions to both implicit functions. In particular, if we consider the case where *a*=*b*=*d*=*γ*=0.5, W=2 and E=5000, we may notice that $(\mu_0^* = 0.87,\ C_0 = 1.05, \theta_0 = 0.001)$ is a solution to $f_1(\mu_i^*, C_i) = 0$ and $f_2(\mu_i^*, \theta_i) = 0$. By substituting these values in $\frac{\partial f_1(\mu_i^*, C_i)}{\partial \mu_i^*}$ and $\frac{\partial f_2(\mu_i^*, \theta_i)}{\partial \mu_i^*}$ we obtain the following: $\frac{\partial f_1(\mu_0^*, C_0)}{\partial \mu_0^*} = \frac{\partial f_2(\mu_0^*, \theta_0)}{\partial \mu_0^*} = 0.988$. Therefore, the condition $\frac{\partial f_1(\mu_0^*, C_0)}{\partial \mu_0^*} = \frac{\partial f_2(\mu_0^*, \theta_0)}{\partial \mu_0^*} \neq 0$ is met.

Therefore, in the intervals above functions $\mu_i^* = g_1(C_i)$ and $\mu_i^* = g_2(\theta_i)$, as well as first-order derivatives $g_1'(C_i)$ and $g_2'(\theta_i)$, do exist. Nonetheless, they still remain implicit functions that can be hardly manipulated and expressed in explicit form[10]. The behaviour of μ_i^* with respect to changes of C_i and θ_i, however, can be still derived through numerical simulations by assuming plausible values for d, b, a, γ, E and *W*.

3.2. Numerical Simulations and Implications

To understand model outcomes and implications through numerical simulations, it is helpful to make the units of measure explicit:

Model variable		*Units of measure*
U^A	Researcher's utility	(Proportional to) Number of publications/patents (or other measurable research results)
U^P	Funding institution's utility	(Proportional to) Social benefit expressed in hundred thousand €
θ	Researcher's ability	Number of publications/patents per working day and per cost unit (one hundred thousand €) spent on the research project
e	Researcher's effort	Number of working days on the project
C	Project cost	Hundred thousand €
E	Researcher's (effort) endowment	Number of total working days
W	Researcher's (financial) endowment	Hundred thousand €
μ	Cofinancing rate	Pure number $\in [0,1]$
$d, b, a, \gamma, \varphi, \rho$: Unknown and invariant model parameters[11]		

[10] The analytical derivation of $f_{1C}(\mu_i^*, C_i)$, $f_{2\theta}(\mu_i^*, \theta_i)$, $f_{1\mu}(\mu_i^*, C_i) = f_{2\mu}(\mu_i^*, \theta_i)$, $g_1'(C_i)$ and $g_2'(\theta_i)$ is available upon request. Looking at (17) we could argue that functions $f_1(\mu_i^*, C_i)$ and $f_2(\mu_i^*, \theta_i)$ can be also written as $f_1(\mu_i^*, C_i) = F_1[e^*(\mu_i^*, C_i)] = 0$ and $f_2(\mu_i^*, \theta_i) = F_2[e^*(\mu_i^*, \theta_i)] = 0$ where function $e^*(\cdot)$, in fact, expresses (5). Therefore, we can rewrite derivatives in (19a) and (19b) as $f_{1C}(\mu_i^*, C_i) = F_{1C}(\cdot)\frac{\partial e_i^*}{\partial C_i}$, $f_{2\theta}(\mu_i^*, \theta_i) = F_{2\theta}(\cdot)\frac{\partial e_i^*}{\partial \theta_i}$ and $f_{1\mu}(\mu_i^*, C_i) = f_{2\mu}(\mu_i^*, \theta_i) = F_{1\mu}(\cdot)\frac{\partial e_i^*}{\partial \mu_i} = F_{2\mu}(\cdot)\frac{\partial e_i^*}{\partial \mu_i}$, respectively. Though we know the signs of derivatives $\frac{\partial e_i^*}{\partial C_i}$ and $\frac{\partial e_i^*}{\partial \mu_i}$ from (7) and (9), however, still we can not be conclusive with respect to the signs of derivatives (19a) and (19b) as we do not know, *a priori*, the signs of $\frac{\partial e_i^*}{\partial \theta_i}$, F_{1C}, $F_{1\theta}$ and $F_{1\mu} = F_{2\mu}$. These signs will depend on the values of model parameters and independent variables d, b, a, γ, E and *W*.

[11] d, b, a, ρ are return coefficients. φ indicates the average social value of a research outcome and is measured in hundred thousand € per research result (publication, patent, etc.). γ makes the results obtained in alternative

By attributing plausible and acceptable ($0 < b < 1$) values to d, b, a, γ, E, W and C (or θ) it becomes possible to compute how e^* varies in response to μ and θ (or C), and how μ^* varies in response to θ (or C). In the case of e^*, numerical simulations are expected to confirm derivatives (7)-(9). In the case μ^*, on the contrary, simulations aim at illustrating the behaviour implied by the reduced form of the model, i.e., equation (18).

Evidently, many different combinations of parameters can be used to compute e^* and μ^* according to (5) and (18). Nonetheless, we can distinguish among general *cases*. Such distinction can be made on the basis of two major aspects. Firstly, the returns to research activities: we can consider the cases of decreasing or increasing returns to scale ($a+b+d<1$ or >1, respectively) as well as the cases of equal or different returns to the different research inputs ($a=b=d$ or $a \neq b \neq d$, respectively). Secondly, we can consider the size of the research project and of the researcher distinguishing researchers with small endowment in terms of both effort and financial resources compared to the project requirements (that is, $E \approx e$ and $W \approx C$, respectively) from researchers with a large endowment (that is, $E >> e$ and $W >> C$).

Under these alternative specifications of d, b, a, γ, E, W [12], figures 3-5 report the numerical simulations computed on (5). They reproduce derivatives (7)-(9), that is, how e^* responds to variations of μ, θ and C. Figures 5-7 report analogous simulations on implicit function (18) showing how μ^* responds to variations of θ and C accordingly. Figures 3-5 confirm the expected behaviour of derivatives (7)-(9). In the first and the third case (e^* depending on μ and C), the response qualitatively does not change regardless the values of d, b, a, γ, E, W: e^* always decreases as μ increases while it increases with C. On the contrary, it may increase (when $d>1$ and, thus, $a+b+d>>1$) or decrease (when $a+b+d<1$) as θ grows.

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research activities comparable to those obtained within the research project under question; thus, it is a pure number. As mentioned, however, neither parameter φ nor ρ influence the value of e_i^* and μ_i^*. In running numerical simulations, their value is specified only to warrant that the principal's participation constraint (see (10c) is respected.

[12] Note that for any simulation it is possible to find plausible values of $\varphi, \rho > 0$ for which the principal's participation constraint in (10c) is respected. For instance, in Case 5 of Figure 6 this occurs with $\rho = 0.20$ and $\varphi = 60$.

The same occurs with μ^* (Figures 6-7): regardless d, b, a, γ, E, W, μ^* always decreases as C increases but always increases with θ[13].

Despite this quite univocal behaviour, the different specifications of research returns and researcher's endowment may still affect the shape of curves in Figures 3-5[14]. The relation between e_i^* and μ_i^* is always convex but the degree of convexity increases with $a+b+d>1$ and small researcher's endowment ($W \approx C$). A larger researcher's endowment, on the contrary, increases the degree of convexity of e_i^* as function of θ_i when $a+b+d<1$. With $a+b+d>1$, $e_i^* = f(\theta_i)$ becomes an increasing and concave function. The increasing function $e_i^* = f(C_i)$, finally, can be either convex or concave, this latter behaviour only occurring with $a \geq b=d$ and $a+b+d \leq 1$ and with large researcher's endowment. This functional behaviour has a straightforward economic explanation on the fact that, from researcher's perspective, higher ($a+b+d$) makes effort spent in the project relatively more productive and larger researcher's endowment makes resources spent within the project relatively less scarce.

Much less intuitive is the experimental behaviour of functions $\mu_i^* = g_1(C_i)$ (Figure 6) and $\mu_i^* = g_2(\theta_i)$ (Figure 7). The former is a decreasing and almost linear function (only slightly concave with $a+b+d>1$ and $W \approx C$), while the latter is increasing and concave regardless returns parameters (d, b, a, γ) and researcher's endowment (W, E), though these parameters may affect how marked concavity is. The economic explanation is that an increasing cost of the project more and more induces, as mentioned, a greater researcher's effort within the project and, thus, the funding institution can increasingly reduce its cofinancing rate still preventing the researcher from exiting the contract. This is more manifest when the financial size of the researcher (W) is large and project returns high ($a+b+d>1$).

Figure 8 summarizes the optimal contractual mechanism implied by the model and by these simulations. On the basis of the observable technical and scientific content of the project, thus C_i and θ_i, the funding institution proposes the contract (μ_i,) to the researcher. This latter, in turn, pursues his maximum utility and opts for the consequent optimal effort on

[13] Figures 6 and 7 only report those solutions of $f_1(\mu_i^*, C_i) = 0$ and $f_2(\mu_i^*, \theta_i) = 0$ that are plausible, i.e. $0 \leq \mu_1 \leq 0$, and real (thus, not imaginary). For any simulation, only one plausible solution is found.

[14] These functional behaviours could be evidently derived even by taking second-order derivatives of (5) with respect to μ, θ and C.

the research project. Within this contractual mechanism, both players eventually achieve the maximum utility from the project. The figure illustrates such mechanism under two different exemplary cases, that is, when $a+b+d>1$ and $W\geq C$ (Case A), and when $a+b+d<1$, and $W>>C$ (Case B). Eventually, for a given project cost C_i , different cases may induce a significantly different cofinancing rate μ_i, and, therefore, a different level of researcher's effort. Thus, if observable, the relationship between C_i and μ_i may be informative also about the underlying unobservable model parameters and variables.

We can now ask whether these relationships between observable variables μ_i, C_i and (partially observable) θ_i (while e_i is, in fact, hardly observable) can be empirically assessed, thus supporting the theoretical derivation of the model, and which parameters' values can be eventually deduced from real observations.

4. The empirical application

4.1. Functional specification

Of major interest here is the relation between the observable cofinancing rate (μ_i^*), the observable cost of the project (C_i) and the ability of the researchers (θ_i). Actually, θ_i can not be directly observed but the funding institution can still conjecture on (and proxy) it on the basis of the available information. To empirically assess the actual funding institution's behaviour, we need an explicit specification of $\mu_i^* = f(\theta_i, C_i)$. This specification has to be, at once, empirically tractable and a good approximation of the underlying theoretical relation (18).

Though linearization of (18) is not affordable, it remains possible to approximate it with a second-order Taylor polynomial and, in particular, with a generalized quadratic function (or flexible function) (Chambers, 1988). Within this family, the most widely used specification is the translogarithmic (or translog) function. The unknown function $\mu_i^* = f(\theta_i, C_i)$ can be approximated, at the approximation point $C_i = 1$ and $\theta_i = 1$, by the following empirical specification[15]:

[15] $\alpha_{ij} = \alpha_{ji}$ due to symmetry.

(20a)

$$\ln \mu_i^* = \ln[f(\theta_i, C_i)] \approx \alpha_0 + \alpha_1 \ln C_i + \alpha_2 \ln \theta_i + 1/2\,\alpha_3 (\ln C_i)^2 + 1/2\,\alpha_4 (\ln \theta_i)^2 + \alpha_5 \ln C_i \ln \theta_i$$

At the approximation point, the value, the first and the second-order derivatives of this function correspond to the unknown function $\mu_i^* = f(\theta_i, C_i)$. Through the estimation of (20a), therefore, it becomes possible to empirically asses how μ_i^* varies in response to C_i and θ_i.

4.2. Data and model variables

(20a) is here applied to the agro-food R&D activity funded by the Italian Region Emilia-Romagna over years 2001-2006, according to the cofinancing pluriannual programme promoted with regional law LR 28/98 (Materia, 2008)[16]. This regional law represents an exemplary case of competitive funding as it implies a selection of submitted projects (1221 over the period under consideration) firstly performed by a panel of external and independent experts (*peer-reviewers*). They assign an evaluation score to any project based on its purely technical and scientific merit. This evaluation is then followed by a further approval-stage controlled by the competent regional bureau that finally admits the projects to public funding. On selected projects (589 over the whole period), the Region must then decide the rate of cofinancing. This funding mechanism does not impose any constrain on other possible research activities the researcher can carry out in parallel. The researcher can eventually even reject the cofinancing rate offered by the Region and, thus, skip the contract. Therefore, the two contractual clauses mentioned in section 2.2 are, formally or informally, in force. The same holds true with the third clause: though not always explicit in the contract, the region can condition the final payment to *in-itinere* and *ex-post* evaluation of results or can even exclude the researcher from successive funding programmes if a negative evaluation of results now emerges. Therefore, LR 28/98 is a concrete case of a public agricultural R&D funding programme whose mechanisms seem very close to the contract modelled in previous sections.

The dataset contains n=589 observations (projects) for which the following information are available: project cost (total budgeted expenditure) (C_i); the percentage (rate of) cofinancing granted by the Region (μ_i); score assigned by the *peer-reviewers* (p_i); project

[16] Region Emilia-Romagna made these data available under the research project untitled “Valutazione della spesa per ricerca, sperimentazione e sviluppo tecnologico in agricoltura: la legge 28/98” (“Evaluation of expenditure for agricultural research and technological development: law 28/98”) funded by the Region itself and carried out by the Associazione Alessandro Bartola (Esposti et al., 2010).

typology in terms of sector of application (s_i); year of funding (t_i)[17]. Table 1 reports some descriptive statistics of these model variables within the sample.

Though θ_i remains unobservable, variable p_i is, from the Region's perspective, a good proxy of the ability attributable to the *i-th* researcher/project. Dummy variables are included to admit that model parameters vary across sub-samples. In particular, a sectoral typology (s_i) is assigned according to what established in LR 28/98 itself. Projects are classified across three sectors: crop productions (VEG); animal productions (ZOO); farm and rural development, environment and marketing (ALT). These typologies actually represent quite different research activities as largely acknowledged in the literature in particular with reference to the comparison between crop and livestock research (Townsend and Thirtle, 2001). Therefore, it seems fully plausible to envisage different model parameters and, consequently, funding institution's behaviour across the different research typologies. Within the adopted empirical model, such heterogeneity is accounted for by simply including sector-specific dummies associated to the constant terms and to the parameters of C_i (see (20b)).

A final aspect to be considered is the possible different behaviour, *ceteris paribus,* depending on the year of funding (t_i). The funding institution can opt, in fact, for a lower (higher) cofinancing rate in years when the overall budget for research is lower (higher)[18]. Under LR 28/98 a progressive reduction of the available budget can be detected, especially for the final years. To capture this increasing overall budget constraint, two time dummies are added taking value = 1 for projects whose funding year (t_i) is 2005 and 2006[19].

Eventually, the estimated model is the following:

(20b)

$$\ln\mu_i = \left(a_0 + \sum_{s=VEG}^{ZOO} a_s D_{si}\right) + \sum_s a_{1s} D_{si} \ln C_i + a_2 \ln p_i + 1/2\, a_3 (\ln C_i)^2 + 1/2\, a_4 (\ln p_i)^2$$
$$+ a_5 \ln C_i \ln p_i + \sum_t a_t D_{ti} + \varepsilon_i, \quad i = 0,...,589;\ s = VEG, ZOO, ALT; t = 2005, 2006$$

[17] Project duration is also an available information but it has been dropped as it is strongly collinear with total project cost (Materia and Esposti, 2009).

[18] A lower budget may generate an higher opportunity cost of a funded research project, that is, an higher reservation utility.

[19] Table 1 shows that the number of funded project gradually decreased over years and this decline is particularly evident in years 2005 and 2006.

where D_{ti} are time dummies and D_{si} sectoral dummies; ε_i is the conventional i.i.d. disturbance term: $\varepsilon_i \sim N\left(0,\sigma^2\right)$. If we exclude sectoral heterogeneity (sectoral dummies) the model "collapses" to the following specification:

$$\text{(20c)} \quad \begin{aligned} \ln\mu_i &= a_0 + a_1 \ln C_i + a_2 \ln p_i + 1/2\, a_3 (\ln C_i)^2 + 1/2\, a_4 (\ln p_i)^2 + a_5 \ln C_i \ln p_i \\ &+ a_5 \ln C_i \ln p_i + \sum\nolimits_t a_t D_{ti} + \varepsilon_i, \quad i = 0,...,589;\ t = 2005,2006 \end{aligned}$$

As the translog specification is here adopted as a local approximation of *f(***x***)* at $\mathbf{x} = 1$ ($\ln \mathbf{x} = 0$), it is helpful, before estimation, to normalize all model variables (excluding the dummies) with respect to the sample mean (by subtracting the mean) such that the approximation is exact in the sample mean point. From (20b), the elasticity of μ with respect to *C* and *p* can be easily computed as follows:

$$\text{(21a)} \quad \partial \ln\mu_i / \partial \ln C_i = \sum\nolimits_s a_{1s} D_{si} + a_3 \ln C_i + a_5 \ln p_i$$

$$\text{(21b)} \quad \partial \ln\mu_i / \partial \ln p_i = a_2 + a_4 \ln p_i + a_5 \ln C_i$$

In the sample mean point, therefore, these elasticities simply become a_{1s} and a_2, respectively, and it is also straightforward to compute the first and second order derivates. It is: $\partial\mu_i / \partial C_i = a_{1s}$, $\partial^2 \mu_i / \partial C_i{}^2 = a_3 - a_{1s}$, $\partial\mu_i / \partial p_i = a_2$, $\partial^2 \mu_i / \partial p_i{}^2 = a_4 - a_2$. In any other sample point or sub-sample mean such elasticities and derivatives may assume different values and signs according to the respective values of C_i and p_i.

It must be finally taken into account that the dependent variable ($\ln\mu_i$) may evidently vary within a finite interval. On the one hand, the maximum value of μ_i is 1, thus the distribution of the dependent variable is right-censored at 0. On the other hand, though in principle the minimum value of μ_i is 0 (in such case $\ln\mu_i$ would not have a lower bound), in practice the application of LR 28/98 has acknowledged a minimum cofinancing rate of 45%, the justification being that a too low cofinancing rate would discourage even capable researchers to submit projects thus inducing adverse auto-selection (Materia and Esposti, 2009). Therefore, it is always $\mu_i \geq 0{,}45$ and the distribution of $\ln\mu_i$ is also left-censored at -0,80. Estimation of (20b,c) has to appropriately take into account this censored-normal distribution of the dependent variable.

5. Model estimates

Three alternative estimates are performed. Firstly, equation (20b,c) is estimated as a classical linear regression model using an OLS estimator. Then, the two distribution limits are introduced in sequence. Firstly, a right-censored (at $\ln \mu_i = 0$) normal distribution and then a left ($\ln \mu_i = -0{,}8$) and right-censored distribution is assumed. Equation (20b,c) becomes a *censored-normal regression* and can be estimated through a Maximum Likelihood (ML) estimator[20]. Unlike OLS estimates, these latter estimates are consistent under a censored distribution, provided that $\varepsilon_i \sim N\left(0, \sigma^2\right)$ (Cameron and Trivedi, 2005; McDonald, 2009)[21]. Table 2 reports the three model estimates. As there is a significant amount of empirical studies underlying the different performance of agricultural R&D activities according to the application sector (Townsend and Thirtle, 2001), an initial objective here is to assess possible differences among groups VEG, ZOO and ALT. The first columns of Table 2 concern estimates of (20c) applied to these sectoral sub-samples. It may be firstly noticed that, compared to OLS, ML estimation generally provides more statistically significant parameters under both right censoring and left and right censoring, in particular for variables of major interest, ln*C* and ln*p*. As a matter of fact, though left censoring concerns many observations (78 projects, overall), estimates with only right-censoring and with censoring on both tails are quite similar (as confirmed by χ^2 tests), with the only exception of group VEG. To avoid repetitions, only left and right-censored ML estimates will be commented and discussed further.

The most relevant evidence emerging from model estimates on sub-samples concerns the different behaviour of ln*C* and ln*p* in the sample mean point, namely the different sign and statistical significance of parameters a_1 and a_2[22]. For VEG projects, presumably an highly

[20] What we call here *censored-normal regression* is more often known as Tobit model, or type-I Tobit model (Wooldridge, 2002). As clarified by Wooldridge (2002, 517-520), the present application should be not even considered a case of censoring as it is rather a "corner solution model". From the econometric point of view, however, it raises exactly the same issues and can be thus legitimately considered a two-limit Tobit model. More details on this, as well as on the comparison between OLS and Tobit estimates, can be found in McDonald (2009).

[21] It can be shown (Wooldridge, 2002) that the OLS bias under censoring increases as the fraction of sample that is censored increases.

[22] It must be reminded that censoring makes the relation between variables non-linear at the extreme points of the distribution. This intrinsic non-linearity actually emerges, though indirectly, in OLS estimates where only parameters associated to quadratic terms are statistically significant. As a consequence, marginal effects differ between censored and uncensored observations. They still correspond, however, to parameter estimates for the (uncensored) latent variable, that is, the unobserved dependent variable for which the linear relation with the

heterogeneous group, a_1 estimate is not statistically different from 0, while it is significant and negative (positive) in the case of ALT (ZOO) groups. On the contrary, a_2 estimate is negative and significant for VEG, while it is not significant for the other two sectors, though positive for ALT and negative for ZOO. Quadratic terms of ln$C$ and ln$p$ behave homogeneously across groups, as respective parameters are always negative though statistical significance differ across sectors (both parameters are significant in ALT, none in ZOO). Parameters associated to time dummies are always negative, as expected, though both significant only for group VEG.

Model estimations on sub-samples, however, does not fully exploit the available statistical information. To achieve better and more robust estimates, Table 2 also reports (last columns) model estimates on the whole sample with or without the introduction of sectoral dummies. In the former case, corresponding to (20b), sectoral dummies allow for some different model parameters (a_s and a_{1s}) across sectors. In the latter estimate, (20c), the between-sector heterogeneity is ruled out as parameters are assumed constant across the whole sample. It follows that specification (20b) represents the best compromise between the maximum exploitation of degrees of freedom granted by the whole-sample estimation without sectoral dummies, and the appropriate consideration of the manifest heterogeneity across sectoral typologies as emerged from sub-samples estimation.

The heterogeneity across sectoral groups is confirmed by the estimation performed on the whole sample without sectoral dummies. For both key model parameters (a_1 and a_2) estimates are not significant. On the contrary, significant estimates are obtained for parameters for which no relevant heterogeneity, or a strongly prevailing relation, emerged in sub-sample estimations (those associated to quadratic and interaction terms and to time dummies). This estimate, though poor, indirectly confirms that the relations between μ and $p(\theta)$ and, above all, between μ and C do differ across the different research typologies. It also confirms that specification (20b) should be preferred for its capacity to take into account such heterogeneity.

Therefore, it should not surprise that estimation of (20b) (last three columns of Table 2) generates better results in terms of statistical significance. Parameter a_1 is now consistent

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independent variables always holds true. Only in this sense, estimated parameters can be interpreted as marginal effects (Wooldridge, 2002; Cameron and Trivedi, 2005).

with what obtained in separate estimations: it is not statistical significant for VEG though negative, significantly positive for ZOO and significantly negative for ALT. Most of other parameters are statistically significant, with the exception of the interaction terms and, in part, of a_2 itself as it is weakly significant, and negative, only under left and right censored ML estimation. This parameter value confirms what obtained for VEG group in sub-sample estimation as the larger sample size of this group evidently tends to prevail on others.

Parameter associated to further sectoral dummies a_{VEG} and a_{ZOO} are weakly and not statistically significant, respectively, thus indicating that, although a residual heterogeneity may remain within the whole sample, this has been mostly captured by the sector-specific parameter a_{1s}. Time dummies, in turn, are univocal across typologies: always statistically significant and negative, thus confirming that the progressive reduction of available budget also reduces, *ceteris paribus*, the cofinancing rate the funding institution is willing to grant.

To better compare estimation results with model implications, the estimation of first and second order derivatives and of elasticities of μ with respect to C and $p(\theta)$ is helpful (Tables 3 and 4)[23]. $\partial \ln \mu_i / \partial \ln C_i$ is not statistically different from 0 in VEG group, while it is positive and significant for ZOO, negative and significant for ALT. According to the model development in section 2 and the respective simulations in section 3 (Figures 6 and 7), only a negative elasticity and a weak concavity of μ with respect to C are admitted. Therefore, results suggest that ALT and VEG projects are consistent with this behaviour while it is the opposite in the case of group ZOO. Sector VEG, actually, does not show a significant relation between μ and C but this could be explained by the specific underlying values of model parameters (high returns and large researchers' endowment) as in Cases 4 and 5 of Figure 6. In addition, also the relevant within-group heterogeneity presumably makes a significant relationship hardly identifiable.

On the contrary, the relation between μ and $p(\theta)$ is expected to be positive and concave according to Figure 7. By looking at the estimated $\partial \mu_i / \partial p_i$ and $\partial^2 \mu_i / \partial p_i^{\ 2}$, this is confirmed only for group ALT, where the former is, in fact, not statistically significant. In general terms, looking at first and second order derivatives, it clearly comes out that only the ALT projects strictly respect model predictions. In the case of the other two groups, estimates

[23] It is worth reminding that in sub-samples' mean points elasticities and derivatives do not simply correspond to estimated parameters as these estimates have been obtained on the whole sample.

could be interpreted either as a rejection of the underlying theoretical framework or as the consequence of the fact that p is only a poor proxy of θ at least for such kind of projects. In the former case, one major explanation could be that the funding institution is not really convinced that the researcher refrains from moral hazard behaviour, that is, it is not convinced that the third contractual clause is really effective in this respect. In the latter case, though the funding institution believes that moral hazard does not occur, it does not trust the score assigned by the *peer-reviewers* and may try to infer ability from other mostly informal and less objective sources. A final reason why model expectations are not supported by empirical results at least for some types of projects (ZOO, in particular) could be the misspecification of the research "production function" in sections 2 and 3. Here, ability, effort and cost have been assumed as substitutes but this can be not necessarily the case especially for the more complex research projects.

6. Concluding remarks

The theoretical model developed in this paper aims at analyzing how a funding institution supports agricultural research activities by designing optimal cofinancing contract with selected researchers. The model wishes to demonstrate that, under certain conditions and by observing some features of the selected researchers/projects, the funding public institution may choose the (optimal) cofinancing rate that induces any researcher to spend the effort that maximizes the utility of both players. Model behaviour, in fact, depends on a set of structural parameters concerning inherent characteristics of researchers and research activities. According to these parameters, the relation occurring between cofinancing rate, project cost and researcher ability may assume different forms.

An empirical application of the model is also presented to assess whether model predictions are confirmed by real data across different typologies of agricultural research. Such application concerns the research programme funded with law LR28/98 by one of the largest Italian Region (Emilia-Romagna) over years 2001-2006. Estimation results seem consistent with the underlying theoretical framework for the research projects of the ALT group (farm and rural development, environment and marketing) and, at least partially, of the VEG group (crop productions). Results concerning projects of the ZOO group (animal productions), on the contrary, are not consistent with model predictions regardless the diverse possible values of model unknown parameters and variables.

This contradictory evidence suggests that both model construction and econometric estimation may deserve further improvements. Possible developments of the theoretical model concern the introduction of risk-aversion in particular for the researcher (Huffman and Just, 2000); moral hazard behaviour of researchers in the second stage of the funding process; an explicit budget constraint for the funding institution; alternative specifications of the utility functions. These further complications of the theoretical framework, however, may hinder empirical tractability. Therefore, steps forward should be also achieved for a more explicit transfer of the underlying theoretical model into an estimable empirical specification to allow for direct estimation and hypothesis testing of model theoretical parameters. As a matter of fact, these latter are not directly estimated in the present application. Results, even when consistent with model predictions, do not allow us to conjecture on all structural parameters (for instance, return parameters) and on possible differences across research groups in this respect.

On the empirical ground, alternative estimation techniques may be also attempted especially to take into account possibly non-linear relations. It could be also helpful to look for a better approximation of the researcher's ability, instead of exclusively using project scores, by more extensively exploiting all the available qualitative and quantitative information on selected and funded projects. This could be also helpful to better detect heterogeneity across and within research typologies particularly in those cases (the VEG group, for instance) where such heterogeneity may hinder an higher statistical significance of estimates.

REFERENCES

Agasisti, T., Catalano, G. (2009): Public Funding and Efficiency of Italian Universities. Paper presented at the 50th Annual Scientific of Meeting of the Italian Economic Society, 22nd-24th October, Rome.

Alfranca, O., Huffman, W.E. (2003): Aggregate private R&D investments in agriculture: The role of incentives, public policies and institutions. Economic Development and Cultural Change, 52, 1–21.

Cameron, A.C., Trivedi, P.K. (2005): Microeconometrics. Methods and Applications. Cambridge: Cambridge University Press.

Chambers, R.G. (1988): Applied production analysis. A dual approach. Cambridge: Cambridge University Press.

David, P.A. (2000): The Political Economy of Public Science. In: Smith, H.H. (ed.), The Regulation of Science and Technology. London: Macmillian.

Esposti, R., Materia, V.C., Sotte, F. (2010): Far lavorare la scienza per il territorio. Le Regioni come agenzie di ricerca agricola. Milano: Franco Angeli.

Esposti, R., Pierani, P. (2003): Public R&D investment and cost structure in Italian agriculture, 1960- 1995. European Review of Agricultural Economics, 30(4), 509-537.

Esposti, R., Pierani, P. (2006): Price, Private Demand and Optimal Provision of Public R&D Investment. An application to Italian agriculture, 1960-1995. Empirical Economics, 31 (3), 699-715.

Gibbons, R. (1998): Incentives in Organizations. Journal of Economic Perspectives, 12 (Fall 1998): 115-132.

Holmstrom, B. (1989): Agency Costs and Innovation. Journal of Economic Behaviour and Organization, 12, 305-327.

Huffman, W.E., Evenson R.E. (1993): Science for Agriculture: a long term perspective. Ames IA: Iowa State University Press.

Huffman, W.E., Just, R.E. (1999a): Agricultural research: benefits and beneficiaries of alternative funding mechanism. Review of Agricultural Economics, 21(1), 2-18.

Huffman, W.E., Just, R.E. (1999b): The organization of agricultural research in Western developed countries. Agricultural Economics, 21, 1-18.

Huffman, W.E., Just, R.E. (2000): Setting efficient incentives for agricultural research:

lessons from principal-agent theory. American Journal of Agricultural Economics, 82, 828-841.

Huffman, W.E., Norton, G., Traxler, G., Frisvold, G., Foltz, G. (2006): Winners and Losers: Formula versus Competitive Funding of Agricultural Research. Choices, 21 (4), 269-274.

Levitt, S.D. (1995): Optimal Incentive Schemes When Only the Agent's "Best" Output Matters to the Principal. RAND Journal of Economics, 26, 744-760.

Materia, V.C. (2008): Il finanziamento pubblico alle attività di R&S in agricoltura. Il caso dell'Emilia Romagna. Paper presented at the Annual Congress of the Italian Society of Agricultural Economics (SIDEA): Politiche per i sistemi agricoli di fronte ai cambiamenti: obiettivi, strumenti, istituzioni, 25th -27 th September, Portici (Naples).

Materia, V.C., Esposti, R. (2009): Selezione e finanziamento pubblico di progetti competitivi di R&S agricola: quanto conta il merito scientifico? Il caso della regione Emilia-Romagna. Rivista di Economia Agraria, LXIV (1-2) (forthcoming).

McDonald, J. (2009): Using least squares and tobit in second stage DEA efficiency analysis. European Journal of Operational Research, 197, pp. 792-798.

Norbäck, P-J., Persson, L. (2009): The organization of the innovation industry: entrepreneurs, venture capitalists, and oligopolists. Journal of European Economic Association, 7 (6), 1261-1290.

Pardey, P.G., Beintema, N.M. (2002): Slow magic: agricultural R&D a century after Mendel. Paper prepared for the 8th Joint Conference on Food, Agriculture and the Environment, August 25-28, Red Cedar Lake, Wisconsin.

Pardey, P.G., Beintema, N.M., Dehmer, S., Wood, S. (2006): Agricultural Research: a growing global divide?. Washington D.C.: International Food Policy Research Institute (IFPRI).

Spielman, D.J., von Grebmer, K. (2004): Public-private partnerships in agricultural research: an analysis of challenging facing industry and the Consultative Group on International Agricultural Research, Washington, D.C., EPTD Discussion Paper No. 113, International Food Policy Research Institute (IFPRI).

Sun, S. (2008): Optimal contract under double-sided moral hazard and Cobb-Douglas production technology. Paper presented at the 2008 International Conference on Risk Management & Engineering Management (ICRMEM), IEEE Computer

Society, 76-81.

Townsend, R., Thritle, C. (2001): Is livestock research unproductive? Separating health maintenance from improvement research. Agricultural Economics, 25, 177-189.

Vagnozzi, A., Di Paolo, I., Ascione, E. (2006): La ricerca agro-alimentare promossa dalle Regioni italiane nel contesto nazionale ed europeo. Quali peculiarità nei contenuti e nella gestione. Rivista di Economia Agraria, LXI (4), pp. 479-518.

Wooldridge, J. (2002). Econometric Analysis of Cross-Section and Panel Data. Cambridge: MIT Press.

Table 1. Descriptive statistics of model variables

Variable	Mean	Minimum	Maximum	Coefficient of Variation
μ	0.82	0.45	1.00	0.19
C	1.685	0.068	16.247	1.16
p	199.02	56	380.00	0.42
Number of granted projects by sector and financing year				
			2001	142
VEG	356		*2002*	114
ZOO	140		*2003*	101
ALT	93		*2004*	96
Total	*589*		*2005*	66
			2006	70

Table 2. Parameter estimates of model (20b,c) (standard error in parentheses)

Sample	*VEG*			*ZOO*			*ALT*			*WHOLE SAMPLE (without sectoral dummies)*			*WHOLE SAMPLE (with sectoral dummies)*		
Estimator Parameter	**OLS**	**ML** (right censored)	**ML** (left and right censored)	**OLS**	**ML** (right censored)	**ML** (left and right censored)	**OLS**	**ML** (right censored)	**ML** (left and right censored)	**OLS**	**ML** (right censored)	**ML** (left and right censored)	**OLS**	**ML** (right censored)	**ML** (left and right censored)
a_0	0.095** (0.029)	0.132** (0.026)	0.143** (0.031)	0.041 (0.030)	0.059* (0.031)	0.062* (0.033)	0.150** (0.057)	0.237** (0.065)	0.324** (0.098)	0.091** (0.019)	0.129** (0.019)	0.141** (0.023)	0.037 (0.037)	0.079** (0.032)	0.077** (0.038)
a_1	-	-	-	-	-	-	-	-	-	-0.005 (0.010)	-0.003 (0.010)	-0.003 (0.012)	-	-	-
a_{1VEG}	-0.014 (0.013)	-0.008 (0.013)	-0.012 (0.015)	-	-	-	-	-	-	-	-	-	-0.014 (0.013)	-0.009 (0.013)	-0.014 (0.015)
a_{1ZOO}	-	-	-	0.051** (0.022)	0.055** (0.019)	0.064** (0.021)	-	-	-	-	-	-	0.053** (0.019)	0.061** (0.022)	0.076** (0.027)
a_{1ALT}	-	-	-	-	-	-	-0.077** (0.030)	-0.098** (0.039)	-0.148** (0.058)	-	-	-	-0.072* (0.037)	-0.085** (0.030)	-0.100** (0.036)
a_2	-0.005 (0.032)	-0.070** (0.033)	-0.081** (0.039)	0.032 (0.037)	0.008 (0.040)	0.013 (0.044)	0.104* (0.063)	0.033 (0.082)	0.104 (0.122)	0.007 (0.022)	-0.049 (0.032)	-0.055 (0.039)	0.004 (0.023)	-0.051 (0.032)	-0.058* (0.033)
a_3	-0.078** (0.024)	-0.092** (0.018)	-0.115** (0.023)	-0.029 (0.036)	-0.033 (0.033)	-0.042 (0.037)	-0.155* (0.086)	-0.188** (0.069)	-0.283** (0.106)	-0.063** (0.019)	-0.073** (0.016)	-0.091** (0.019)	-0.071** (0.019)	-0.082** (0.016)	-0.102** (0.019)
a_4	-0.235 (0.227)	-0.265 (0.176)	-0.322 (0.209)	-0.050 (0.207)	-0.088 (0.187)	-0.101 (0.204)	-1.087** (0.386)	-1.425** (0.429)	-2.237** (0.675)	-0.323** (0.139)	-0.401** (0.127)	-0.492** (0.152)	-0.289** (0.140)	-0.364** (0.125)	-0.440** (0.151)
a_5	-0.030 (0.034)	-0.033 (0.028)	-0.038 (0.033)	-0.094** (0.039)	-0.102** (0.041)	-0.113** (0.045)	0.226** (0.087)	0.262** (0.098)	0.410** (0.153)	-0.018 (0.025)	-0.020 (0.023)	-0.022 (0.027)	-0.023 (0.025)	-0.026 (0.023)	-0.029 (0.027)
a_{VEG}	-	-	-	-	-	-	-	-	-	-	-	-	0.060* (0.035)	0.057* (0.030)	0.071* (0.036)
a_{ZOO}	-	-	-	-	-	-	-	-	-	-	-	-	0.043 (0.038)	0.029 (0.034)	0.046 (0.041)
a_{2005}	-0.115** (0.044)	-0.122** (0.040)	-0.144** (0.048)	-0.082** (0.041)	-0.090 (0.051)	-0.087 (0.055)	-0.094 (0.108)	-0.071 (0.121)	-0.114 (0.174)	-0.093** (0.030)	-0.101** (0.032)	-0.113** (0.039)	-0.097** (0.031)	-0.105** (0.032)	-0.118** (0.038)
a_{2006}	-0.067 (0.043)	-0.083** (0.041)	-0.098** (0.048)	-0.125* (0.068)	-0.124** (0.055)	-0.151** (0.061)	-0.031 (0.136)	-0.018 (0.140)	-0.020 (0.201)	-0.094** (0.033)	-0.102** (0.034)	-0.130** (0.040)	-0.097** (0.034)	-0.107** (0.033)	-0.135** (0.040)
Observations:	356	306 *uncensored* 50 *right-censored*	48 *left-censored* 259 *uncensored* 50 *right-censored*	140	121 *uncensored* 18 *right-censored*	10 *left-censored* 112 *uncensored* 18 *right-censored*	93	67 *uncensored* 26 *right-censored*	21 *left-censored* 46 *uncensored* 26 *right-censored*	589	495 *uncensored* 94 *right-censored*	78 *left-censored* 417 *uncensored* 94 *right-censored*	589	495 *uncensored* 94 *right-censored*	78 *left-censored* 417 *uncensored* 94 *right-censored*
R^2:	0.116			0.203			0.286			0.105			0.133		
LR χ^2 :		43.02**	44.64**		27.81**	29.79**		24.91**	27.21**		57.36**	59.36**		74.08**	77.00**

**,*: statistically significant at 5% and 10% confidence level, respectively

Table 3. Elasticity of μ_i with respect to C_i and p_i computed in the sample mean by groups of research projects (estimation performed on the whole sample with time and sectoral dummies; left and right censored ML estimate

Sub-samples	$\partial \ln \mu_i / \partial \ln C_i$	$\partial \ln \mu_i / \partial \ln p_i$
VEG	-0.014 (0.015)	-0.085** (0.035)
ZOO	0.048** (0.024)	-0.033 (0.027)
ALT	-0.063** (0.032)	0.017 (0.029)

**,*: statistically significant at 5% and 10% confidence level, respectively

Table 4. First and second order derivatives of μ_i with respect to C_i and p_i computed in the sample mean by groups of research projects (estimation performed on the whole sample with time and sectoral dummies; left and right censored ML estimate)

Sub-samples	$\partial\mu_i / \partial C_i$	$\partial^2 \mu_i / \partial C_i^{\ 2}$	$\partial\mu_i / \partial p_i$	$\partial^2 \mu_i / \partial p_i^{\ 2}$
VEG	-0.014 (0.15)	-0.092** (0.026)	-0.080** (0.033)	-0.314** (0.115)
ZOO	0.036** (0.018)	-0.084** (0.018)	-0.036 (0.030)	-0.473** (0.174)
ALT	-0.091** (0.045)	-0.094** (0.050)	0.019 (0.033)	-0.612** (0.215)

**,*: statistically significant at 5% and 10% confidence level, respectively

Figure 1. The two-stage logic of the funding mechanism: selection among competing research projects (1st stage) and cofinancing agreement (2nd stage)

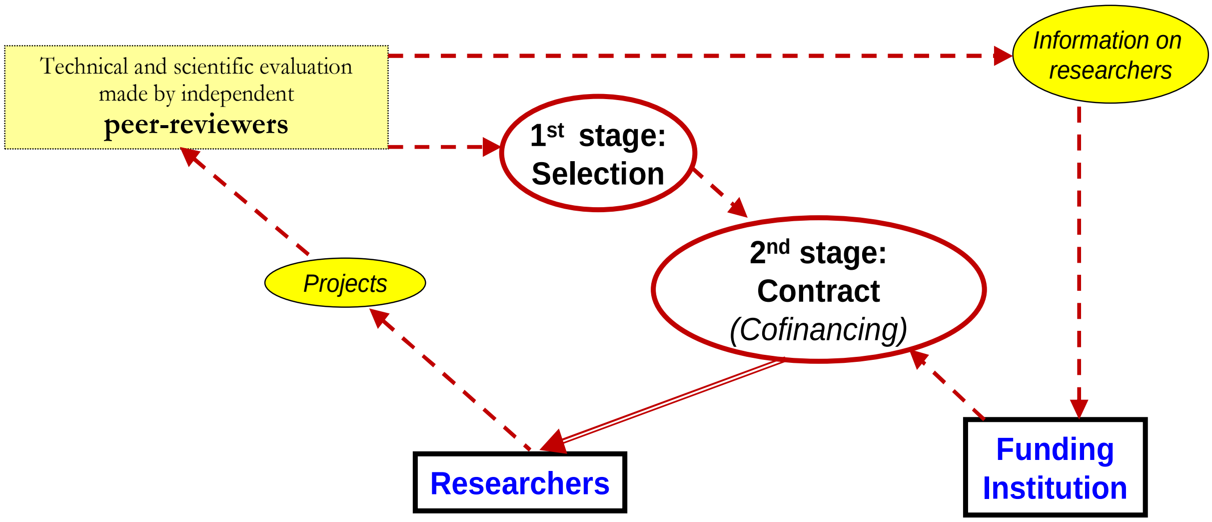

Figure 2. Existence of the contract space: the research contract only exists in the Case B, when the minimum μ accepted by the agent (i.e., that makes his net utility $U_N^A = 0$) is lower than the maximum μ accepted by the principal (i.e., that makes his net utility $U_N^P = 0$)

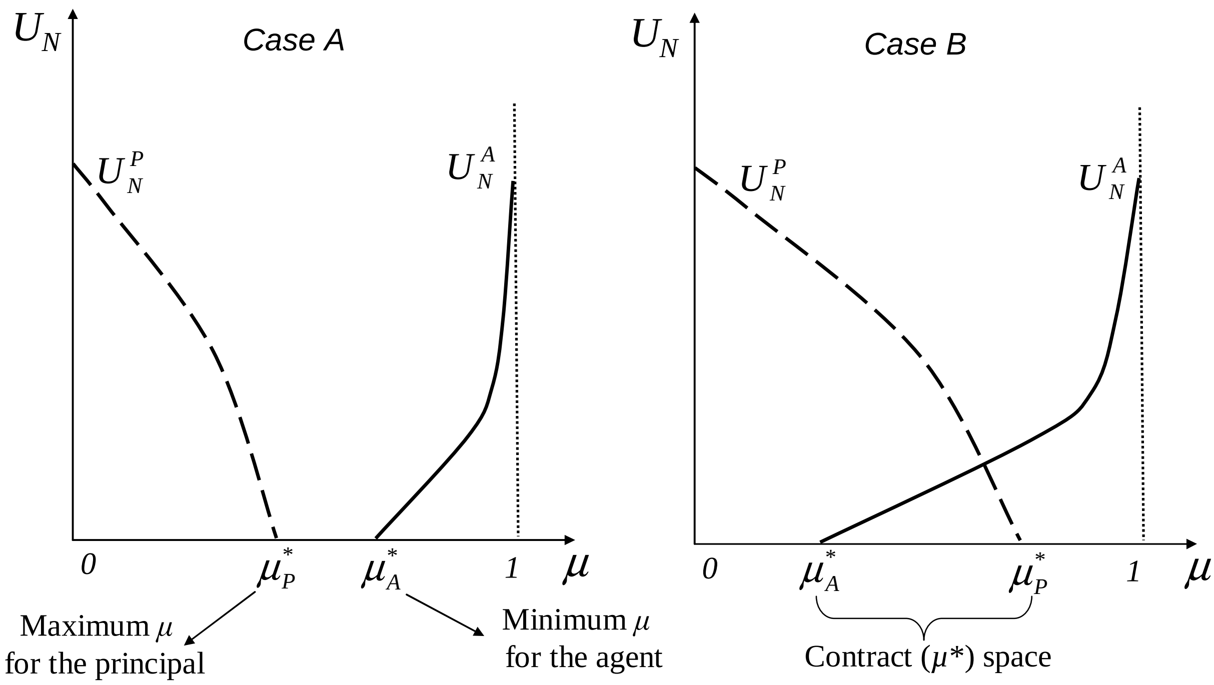

Figure 3. Simulations of the relation between cofinancing rate (μ) and optimal effort (e^*). ***Case 1****: a=b=d=0.33; γ=0.5; θ=0.001; C=1.8; W=2.* ***Case 2****: a=b=d=0.50; γ=0.5; θ=0.001; C=1.8; W=2.* ***Case 3****: a=b=d=0.33; γ=5; θ=0.001; C=1.8; W=2.* ***Case 4****: a= b=d=0.33; γ=0.5; θ=0.001; C=1.8; W=5*

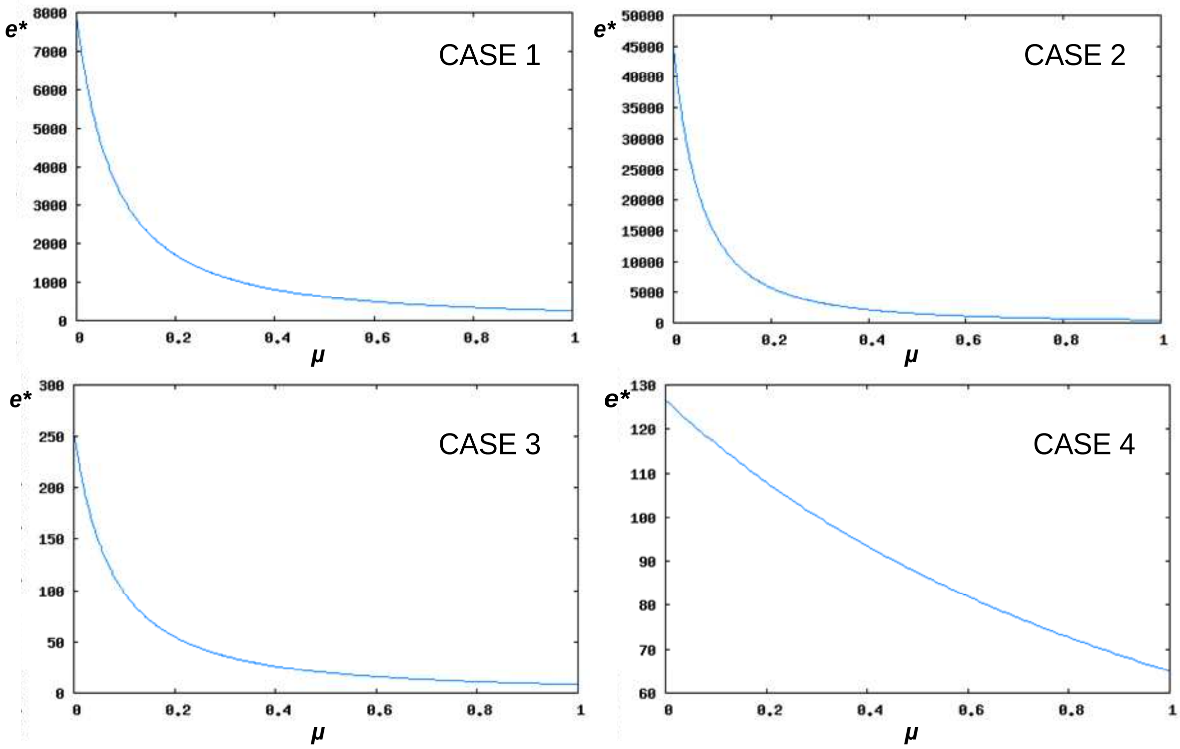

Figure 4. Simulations of the relation between researcher's ability (θ) and optimal effort (e^*). ***Case 1****: a=b=d=0.33; γ=0.5; μ=0.6; C=1.8; W=2.* ***Case 2****: a=b=0.50; d=1.1; γ=0.5; μ=0.6; C=1.8; W=2.* ***Case 3****: a=b=d=0.33; γ=5; μ=0.6; C=1.8; W=2.* ***Case 4****: a=b=d=0.33; γ=0.5; μ=0.6; C=1.8; W=5*

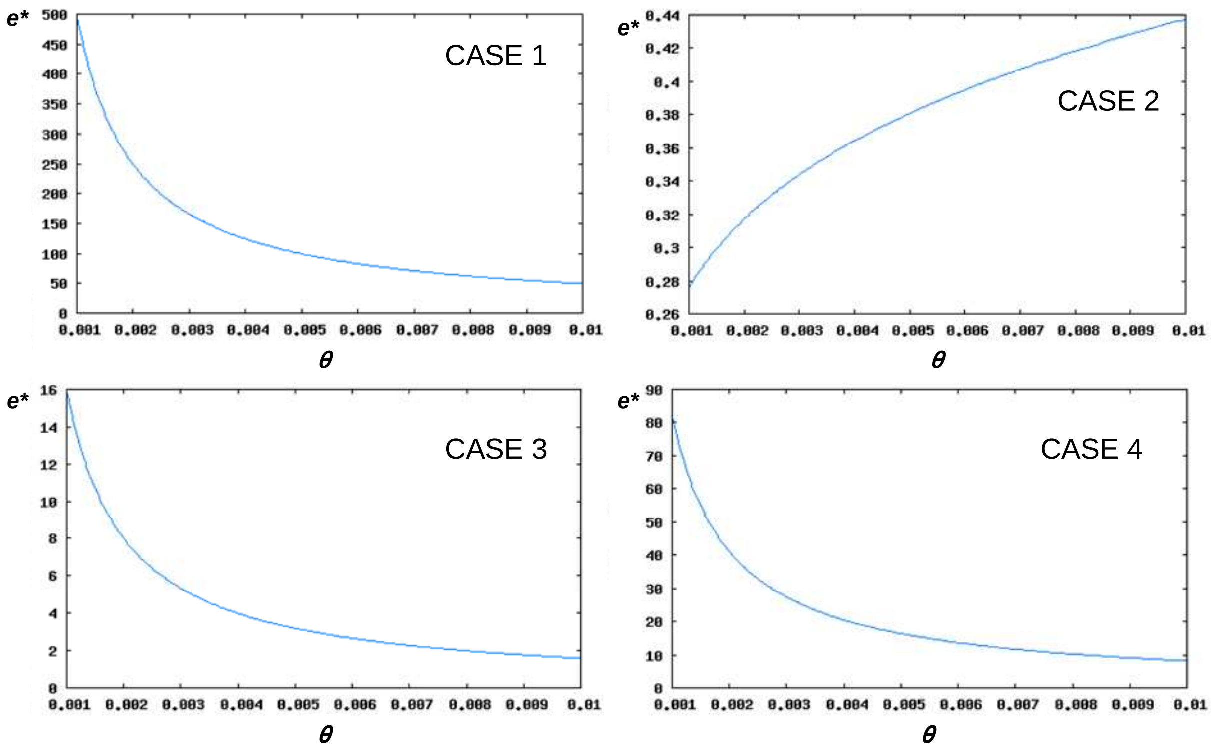

Figure 5. Simulations of the relation between project cost (C) and optimal effort (e^*). ***Case 1****: a=b=d=0.33; γ=0.5; μ=0.6; θ=0.001; W=2.* ***Case 2****: a=1.1; b=d=0.50; γ=0.5; μ=0.6; θ=0.001; W=2.* ***Case 3****: a=0.1; b=d=0.33; γ=0.05; μ=0.6; θ=0.001; W=50.* ***Case 4****: a=b=d=0.33; γ=0.5; μ=0.6; θ=0.001; W=5*

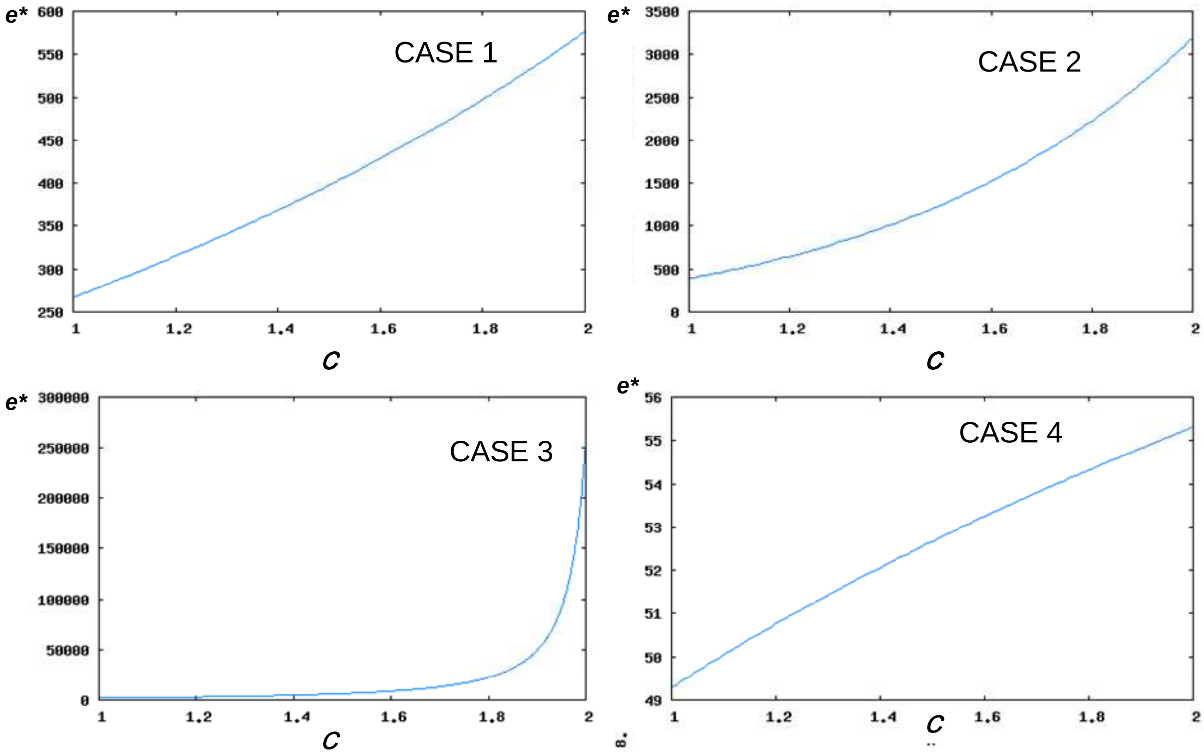

Figure 6. Simulations of the relation between project cost (C) and optimal cofinancing rate (μ). **Case 1**: a=b=d=0.5; γ=0.5; θ=0.001; W=2; E=5000. **Case 2**: a=b=d=0.5; γ=0.5; θ=0.001; W=5; E=5000. **Case 3**: a=d=0.2; b=0.5; γ=0.5; θ=0.001; W=70; E=5000. **Case 4**: a=b=d=0.5; γ=5; θ=0.001; W=50; E=50000. **Case 5**: a=b=d=0.5; γ=0.5; θ=0.001; W=50; E=5000.*

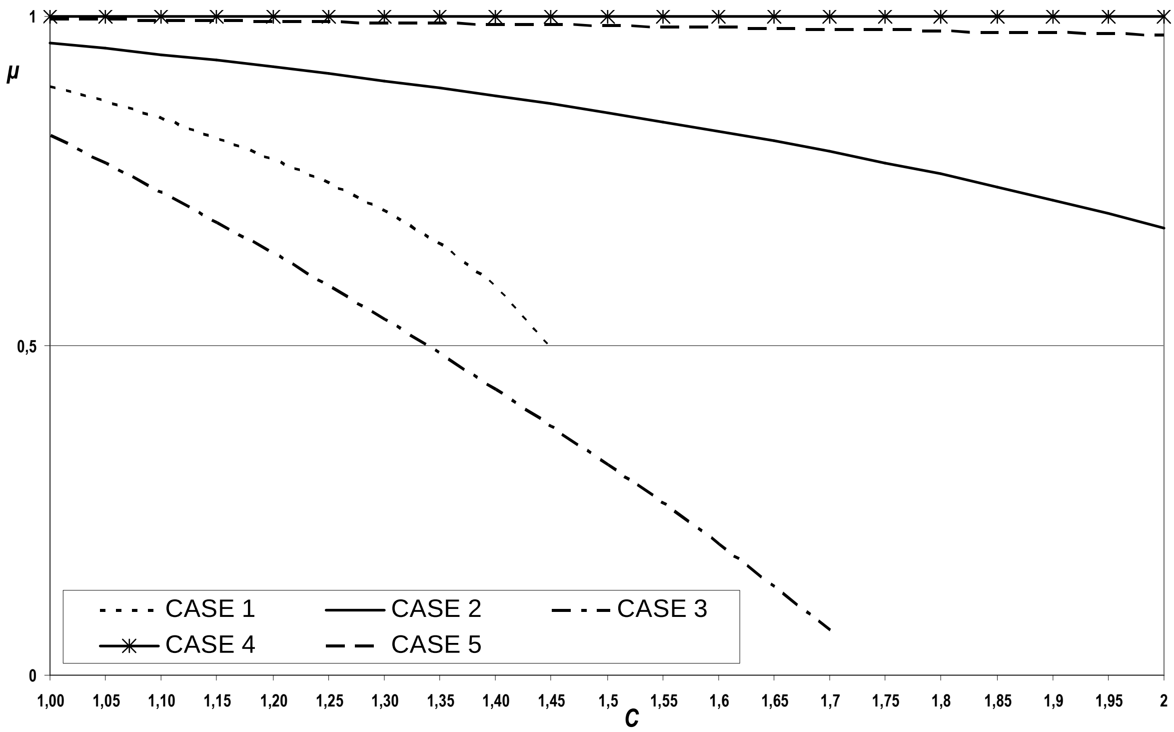

Figure 7. Simulations of the relation between researcher's ability (θ) and optimal cofinancing rate (μ). **Case 1**: a=b=d=0.5; γ=0.5; C=1.4; W=5; E=5000. **Case 2**: a=b=0.2; d=0.5; γ=0.5; C=1.4; W=5; E=5000. **Case 3**: a=b=d=0.5; γ=0.5; C=1.05; W=2; E=5000.*

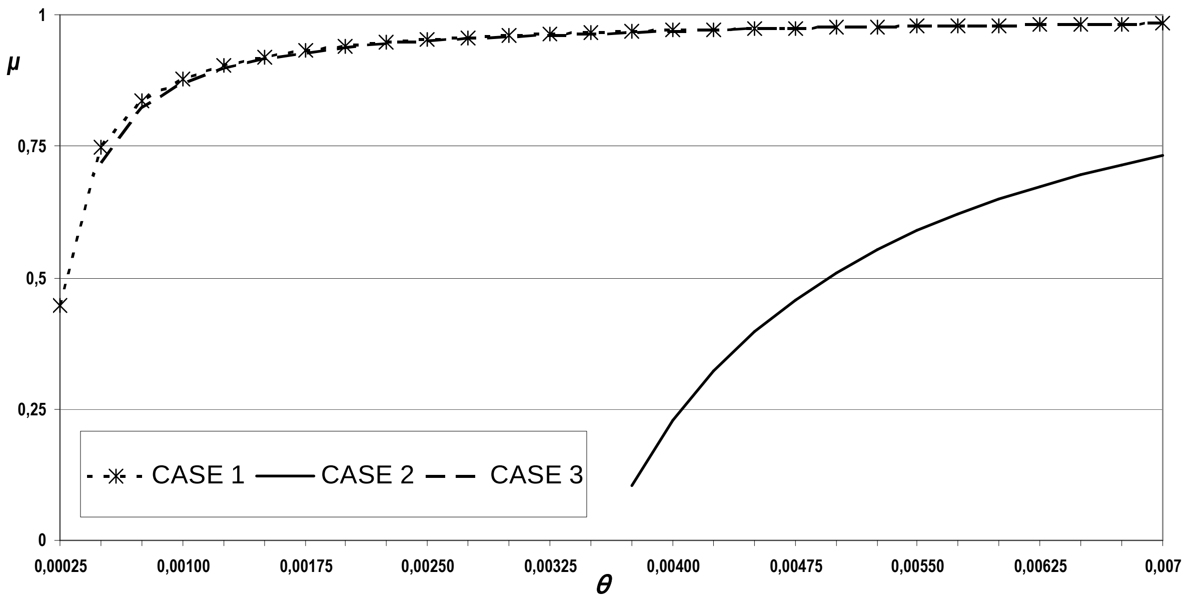

Figure 8. Optimal contract in research cofinancing: relation between project cost, cofinancing rate and researcher effort under different model parameters (Cases) - Case A: a+b+d>1, W≥C; Case B: a+b+d<1, W>>C).