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ARE R&D SUBSIDIES PROVIDED OPTIMALLY? EVIDENCE FROM A SIMULATED AGENCY-FIRM STOCHASTIC DYNAMIC GAME

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Direttore Responsabile
Secondo Rolfo

Direzione e Redazione
Cn -Ceris
Via Real Collegio, 30
10024 Moncalieri (Torino), Italy
Tel. +39 011 6824.911
Fax +39 011 6824.966
segreteria@ceris.cnr.it
http://www.ceris.cnr.it

Sede di Roma
Via dei Taurini, 19
00185 Roma, Italy
Tel. +39 06 49937810
Fax +39 06 49937884

Sede di Milano
Via Bassini, 15
20121 Milano, Italy
tel. +39 02 23699501
Fax +39 02 23699530

Segreteria di redazione
Maria Zittino
m.zittino@ceris.cnr.it

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Are R&D subsidies provided optimally? Evidence from a simulated agency-firm stochastic dynamic game

Cerulli Giovanni

National Research Council of Italy

Ceris - Institute for Economic Research
on Firms and Growth
Via dei Taurini, 19
00185, Roma
g.cerulli@ceris.cnr.it

ABSTRACT: By means of a simulated funding-agency/supported-firm stochastic dynamic game, this paper firstly shows that not only the level of R&D performed by firms is underprovided (as maintained by traditional literature on the subject), but also the level of the subsidy provided by the funding (public) agency (used to correct exactly for the corporate R&D shortage). This event is due to externalities generated by the agency-firm strategic relationship. Two versions of the model are simulated and compared: one assuming rival behaviors between companies and agency, and one associated to the Social-planner (or cooperative) strategy.

Secondly, the paper looks at what "welfare" implications are associated to different degree of funding effect's persistency. Three main conclusions are drawn: (i) the relative quota of subsidy to R&D is undersized in the rival compared to the Social-planner model; (2) the rivalry strategy generates distortions that favor the agency compared to firms; (3) when passing from less persistent to more persistent R&D additionality/crowding-out effect, the lower the bias the greater the variance is and vice versa.

As for the management of R&D funding policies, all the elements favouring greater collaboration between agency and firm objectives can help current R&D support to reach its social optimum.

Keywords: R&D subsidies, Rivalry vs. cooperation, Dynamic-stochastic games, Simulations

JEL CodeS: O38, H2, C73, C63

CONTENTS

INTRODUCTION

It is commonly held that corporate R&D activities need to be subsidized. This occurs because many "market imperfections" might lead to an undersized R&D performance on the part of profit-maximizing enterprises. Generally, the literature has maintained that the "public good" attribute of knowledge (as R&D is approximately meant as a measure of knowledge production) and various other imperfections in markets for the financing of R&D are to be considered the main sources of this distortive phenomenon.

Nevertheless, besides the overwhelming attention paid to explain the potential shortage of private R&D, the literature does not seem to have devoted so far comparable importance to the fact that also the level of public subsidies – decided at political level – could be severely underprovided. Indeed, it can be proved that this phenomenon could depend on two distinct (although correlated) characteristics of the "relation" between the funding agency and the supported units: (i) *externalities* generated by their strategic interaction, (ii) *asymmetric information* between agency and firms in assessing the quality of proposed R&D projects or in the level of effort provided by the firm in implementing its R&D objective. Although both are relevant aspects, the present paper abstracts from point (ii) while emphasizes the consequences of point (i) on both R&D and subsidy provision by means of a "simulated dynamic stochastic game" between a public agency choosing the level of R&D subsidies to be financed and a representative "supported" firm performing R&D.

We set a forward-looking public agency choosing the time profile of subsidies by maximizing the average discounted sum of future values of an objective function assumed to be increasing in R&D (the agency wants to enlarge the national R&D outlay) and concave in the subsidy (as a budget constraint can be at work). Firms, on their part, maximize an instantaneous profit function (myopic assumption) in which R&D costs depend crucially on experience (accumulated R&D stock) and, of course, on subsidies received (plus other costs). At heart of the model there is the effect of the agency's subsidy on firm R&D activity's costs that is crucially modelled as a discrete Markov process with two potential states (positive or negative) to account for path-dependence in firm R&D "additionality" or "crowding-out" behavioural outcome.

Solved computationally, two versions of the model are simulated and compared: one for the agency-firm "rival" strategy and one for the "Social-planner" strategy (maximizing the sum of the two agents' profits that is the "cooperative" strategy), under parameters set up according to model's internal coherence and some stylized facts. The crux of our analysis is the time pattern of the "ratio of subsidies on R&D expenditure" under different degrees of the persistency in the effect of the subsidy on firm R&D outlay. Nevertheless, the dynamic pattern of further endogenous variables such as R&D marginal costs and returns, stock of accumulated knowledge, agency and firm profits and social welfare is also explored.

The paper is organized as follows: in section 2 we briefly review the literature on the rationale for R&D subsidization and present some related works using, as in our case, a simulative approach; in section 3 we present the structure of our model in terms of firm, agency and the Social-planner behavioural assumptions, as well as a description of how we model the path-dependence of the subsidy effect in this context; section 4 is devoted to an explanation of the logical functioning of our model when embedded in a (pivotal) game theoretical perspective; section 5 provides the main (Monte Carlo) simulation results we obtain from running several times our stochastic model, while section 6 closes the paper. Finally, the Appendix placed at the end of the paper provides a "read me" for the attached Matlab code used for performing the simulations.

2. LITERATURE REVIEW

The economic rationale for subsidizing corporate R&D is based on the idea that R&D activity owns some intrinsic characteristics that substantially differentiate it from other usual business activities. Jou and Lee (2001), for example, suggest that R&D is different from other private activities for three major reasons: (i) future rewards to R&D are extremely risky and uncertain, (ii) R&D spending takes the form of an irreversible choice (i.e., it generates hard *sunk costs*), (iii) R&D activities produce positive externalities. Within the literature, R&D subsidization was at the beginning invoked primarily for this third reason as accounted by the pioneering paper by Arrow (1962). The argument is well-known: since R&D activities have classical "public good" characteristics, the level of private R&D outlay would be systematically lower than the socially optimal level. This occurs since the benefits associated to R&D activities are easily and freely available to subjects that are not engaged in R&D efforts. As a consequence, the lack of full appropriability of R&D returns reduces the incentive to investment in knowledge on the part of private for-profit firms and thus government intervention is meant as an effective way to reduce the extent of this "market failure".

Only recently, characteristics (i) and (ii) have been more seriously taken into account for justifying public intervention. In her extensive survey on the subject, Hall (2002) recognizes that, unlike externalities, other market failures associated to R&D activities can be relevant. For instance, when capital markets are imperfect, high-risk investments can severely suffer of credit rationing as the immaterial nature of R&D assets are unable to provide suitable collaterals to financers. In this case the asymmetric information between lenders and borrowers of R&D assets could be extremely high, thus generating higher rationing of funds. This problem is even more straightened in presence of financially constrained firms and undersized venture capital markets. The presence of high barriers to enter and exit the market is another potential source of private

R&D shortage: on one hand, when a great amount of irreversible R&D investment have been done by an incumbent firm, exiting the market could be seriously costly; on the other hand, entering the market could be difficult too as the R&D performed by incumbent firms (as well as their related patenting activity) may generate market power thus weakening free access and competition from external companies (Dasgupta and Stiglitz, 1980; Dasgupta, 1988; D'Aspremont and Jacquemin, 1988). Other motives suggesting the need for R&D support are based on the potential lack of technological infrastructures and bridging institutions, on coordination failure of profitable R&D joint ventures and on an excessive competitive arena leading to duplications in R&D efforts and other wastes of R&D-related resources (Mowery, 1995; Metcalfe, 1995; Malerba, 1993, Martin and Scott, 2000).

No part of this literature has paid attention to the fact that also the R&D public intervention could be severely undersized and sub-optimally provided, although the aim of public support is to correct the market failures associated to low corporate R&D activities. Generally, public intervention is viewed in a Pigouvian perspective where the public agency is thought of as an independent, external and fully informed subject. In this perspective subsidies are thought of as "exogenous injections" rather than as an endogenous outcome of the strategic interplay between financing and financed subjects. Indeed, what we want to stress in this paper is that the public agency is an actor involved (strategically) in a game with financed companies, thus having its own objective function and behavioural strategy. The interaction between the public agency and the (financed) firm strategy generates an externality effect very similar to the Cournot-Nash type of the Prisoner's Dilemma or oligopolistic models, and it can be proved that this form of externality is responsible for an under-provision of the supplied subsidy.

It is worth stressing, however, that in this paper we abstract from a second source of R&D subsidy sub-optimality, that caused by asymmetric information within public agency and financed companies. We only consider, within an optimal stochastic dynamic game, inefficiencies generated by strategic interaction thus ruling out those produced by potential moral hazard or adverse selection.

As for previous literature on the subject, papers using a simulation approach for studying the effect of public subsidies on corporate R&D are very few and generally they do not model directly the public agency objective and behaviour. At micro-level papers of this kind are those by Jou and Lee (2001) and Laincz (2009). The latter embeds the R&D subsidization within a dynamic programming general equilibrium setting *à la* Ericson and Pakes (1995). The author builds a model with forward-looking dynamically optimizing firms where entry and exit decisions determine the dynamic of market structure. R&D subsidies are external interventions rising long-run growth rate and industry concentration as incumbent firms benefit more from them. Nevertheless, the funding-agency behaviour is not explicitly modelled and the R&D subsidy is just viewed as an external injection.

At macro-level, Bental and Peled (2002) provide a calibrated dynamic model of growth in the spirit of endogenous growth models. They estimate the separate effect of restricted and unrestricted R&D subsidies on output and TFP growth, showing that both types of subsidies have significant long-run impact on aggregate performance. Yet, as in the case of Laincz (2009), no funding-agency decision process is represented in the model.

The only paper we have found in the literature explicitly modelling the firm-agency subsidization relationship is that by Materia and Esposti (2009). This study is fairly close in spirit to our setting, although it is primarily interested in analysing only the optimal agency co-financing rate rather than a full set of endogenous variables as in our case. Moreover two important elements distinguish their work from that presented here: (i) it is essentially static as agency and firms maximize instantaneous objective functions, and (ii) it is fully deterministic. Our model, on the contrary, assumes agency's intertemporal optimizing behaviour by also following a specific representation of the corporate R&D determination, the one proposed by David-Hall-Toole (2000). Furthermore our model is stochastic, pays specific attention to path-dependence and is primarily focused on welfare consequences of externalities generated by the agency-firm strategic interdepen-dence.

3. THE MODEL

3.1 Firm behaviour

Our model assumes a profit maximizing firm, choosing the optimal level of R&D investment by equating the marginal rate of return (MRR) and the marginal capital costs (MCC) of R&D as assumed in the model of R&D determination proposed by David, Hall and Toole (2000), hereafter DHT[1]. The R&D rate of return (RR) is $r_t p_t$ where r_t are units of R&D expenditure and p_t the marginal rate of return (MRR) to R&D. According to the DHT model, p_t is assumed to be a decreasing function of r_t. In the linear form we have that:

$$\text{MRR:} \quad p_t = \phi_0 - \phi_1 r_t \quad \text{with} \quad \phi_0, \phi_1 > 0$$

where ϕ_0 represents fixed marginal costs and ϕ_1 a slope parameter controlling for the sensitivity of the MRR to firm R&D choice. The R&D investment capital cost (CC) is $c_t r_t$ where c_t is the marginal capital cost of R&D (MCC). It is assumed to depend (stochastically) on the level of the subsidy and on the level of the R&D experience (R&D accumulated capital stock):

$$\text{MCC: } c_t = \mu - \beta A_t s_t - \gamma k_t \quad \text{with } \beta, \gamma > 0$$

Very concisely, this equation states that the unitary cost of doing R&D is a decreasing function of the R&D capital stock (in so accounting for a "learning by doing"

[1] There is a huge literature on the determinants of firm RDI behavior. See, for instance: Mansfield (1964), Howe and McFetridge (1976), Nadiri (1979), Cohen and Levinthal (1990).

phenomenon) and a function of s_t, the public subsidy, that has a positive impact (a cost reduction) when A_t is equal to 1 and a negative one (a cost increase) when A_t is equal to -1. More precisely, A_t is modelled as a Markov Chain stochastic process taking two states (+1 and -1) with a transition probability matrix depending on a parameter ρ (ranging from -1 and 1) accounting for the degree of "path-dependence". Indeed, when $\rho = -1$, A_t is a fully non-persistent process (and the minimum level of path-dependence is achieved), when $\rho = 0$, a uniform distribution of state transition probabilities over A_t is assumed, while when $\rho = 1$, A_t assumes +1 or -1 constantly (and the maximum level of path-dependence occurs). In this context the meaning of path-dependence deals with two crucial factors: (i) the persistency of succefull/unsuccesfull R&D projects proposed by firms, on one hand, and (ii) the "selection" of supported units operated by the agency on the other. We will come on this point later on the paper.

The firm profit function associated to its R&D activity is:

$$\pi_t^F(r_t, s_t) = r_t p_t - c_t r_t$$

where we have put into evidence that it critically depends on its level of R&D (r_t) and the level of the subsidy decided by the public agency (s_t) through c_t. Given the level of the subsidy received from the agency, the firm chooses its optimal level of R&D expenditure (r_t*) by maximizing its profit under the constrain represented by the law of motion of the R&D capital stock, that is:

$$\begin{cases} r_t* = \arg\max\{\pi_t^F = r_t p_t - c_t r_t\} \\ s.t. \;\; r_t = k_{t+1} - (1-\delta)k_t \end{cases}$$

Now, by simple algebra and deriving by r_t the previous system provides the optimal level of R&D expenditure as a function of A_{t+1}, s_t and k_{t+1}, that is:

$$(1) \qquad r_t* = \xi(\phi_0 - \mu) + \beta\xi A_t s_t + [\xi\gamma/(1-\delta)]k_{t+1}$$

This (analytical) formula explains the firm optimal R&D response to any level of the public subsidy, given the realization of the Markov process, the future level of knowledge stock and the choice of parameters' values. Observe that, according to the path-dependence argument we referred to above, the chain can generate a positive or negative effect of the subsidy on the optimal firm R&D expenditure. From equation (1) we get, by making s_t explicit and employing the R&D capital stock equation:

$$(2) \qquad s_t = \frac{1}{A_t}a_s - \frac{1}{A_t}b_s k_t + \frac{1}{A_t}c_s k_{t+1}$$

where $a_s = (\phi_0 - \mu)/\beta$, $b_s = (1-\delta)/\beta\xi$, $\varphi = (1-\delta-\xi\gamma)/(1-\delta)$, $\xi = (1-\delta)/[2\phi_1(1-\delta)+2\gamma]$ and $c_s = \varphi/\beta\xi$.

Equation (2) turns to be the essential constraint under which the agency calculates the level of its subsidy provision in a dynamic programming environment. It is derived directly from the firm behavior that the agency, in its turn, takes as given.0

3.2 Agency behaviour

The utility function of the agency increases monotonically in r_t while it takes a quadratic form in s_t. Indeed, while the agency profit increases in r_t as the agency wants the firm to produce as many R&D as possible, agency utility first increases in s_t and, after a certain threshold, decreases in it. It happens since the agency is "budget-constrained" and the increase of s_t beyond a certain level provides detrimental effects (inverted U-form), so that:

$$\text{(3)} \qquad \pi_t^A(s_t, r_t) = s_t(1 + r_t) - \psi s_t^2$$

Unlike the case of the firm, the agency is assumed to be forward-looking thus choosing the optimal s_t temporal profile by maximizing - at the beginning of the period – the expected value of the sum of its actualized future profits, given the R&D level chosen by the firms, the law of motion of the R&D capital, the realization of A_t and the values of parameters. More technically – for any firm R&D decision – the agency chooses the profile s_t that solves:

$$\text{(4)} \quad \begin{cases} \max\limits_{\{s_t\}_{t=0}^{\infty}} E_0 \sum\limits_{t=0}^{\infty} \beta^A \pi_t^A(s_t, r_t) \\ s.t. \quad s_t = -\dfrac{1}{A_t} a_s - \dfrac{1}{A_t} b_s k_t + \dfrac{1}{A_t} c_s k_{t+1} \\ r_t = k_{t+1} - (1-\delta) k_t \end{cases}$$

where β^A is the discounting rate of future agency returns and E_0 is the expectation operator at the beginning of the period. By substituting the two constraints for r_t and s_t of (4) into the agency profit function, this latter becomes dependent only on state variables A_t, k_t and k_{t+1}. Hence it takes the typical form of a recursive equilibrium model that can be translated into a Bellman equation and solved computationally. The solution of system (4) is the agency optimal policy function $k_{t+1} = g(k_t)$ according to which it is possible to simulate the temporal path of the variables of interests, such as k_t, s_t, r_t, s_t/r_t, p_t, c_t, π_t^A, π_t^F and derive the movement of the total welfare (w_t) calculated as the sum of agency and firm profits. Of course, given the stochastic nature of this model results for each considered variable are obtained via Monte Carlo simulations. We run 10,000 simulation of the model and calculate averages and standard deviations of the outcomes to characterize the results of variables' equilibrium patterns under diverse degrees of persistency in the subsidy effect on firm R&D.

3.3 Social-planner (or "cooperative") behaviour

A Social-planner makes the choice of maximizing jointly the firm and the agency profit function. It is equivalent to a "cooperative" solution of the game, in which the firm and the agency finds an agreement to "internalize" the externalities generated by their interdependent decisions.

This alternative perspective leads to a dynamic programming problem similar to that seen above, although - this time - the objective function is the *sum of the two players' profit*, that is:

$$(5)\quad \begin{cases} \max\limits_{\{s_t\}_{t=0}^{\infty}} \; E_0 \sum\limits_{t=0}^{\infty} \beta^A \left[\pi_t^A(s_t, r_t) + \pi_t^F(s_t, r_t) \right] \\ s.t. \;\; s_t = -\dfrac{1}{A_t} a_s - \dfrac{1}{A_t} b_s k_t + \dfrac{1}{A_t} c_s k_{t+1} \\ r_t = k_{t+1} - (1-\delta) k_t \end{cases}$$

Solving this new problem leads to a different solution, i.e. a different form of the optimal policy function we indicate in this case with $k_{t+1} = g^{SP}(k_t)$. According to this policy function we can simulate the time path of variables as set out above. The Social-planner solution is our "benchmark" so that, once parameters are set-up, one can compare the *rival* with the *cooperative* solution of the game thus providing interesting "welfare" considerations in terms of the efficient provision of both subsidy and R&D.

3.4 Path-dependence

The effect of path-dependence on our simulations' outcomes is analysed via the behaviour of A_t, i.e. the sign (positive or negative) of the subsidy effect on R&D costs. What do A_t realizations depend on? Very concisely, two elements participate in determining a positive A_t (opposite arguments can be sustained for the negative case): (i) a pure exogenous and independent positive technological shock (*good luck*), (ii) an agency selection of beneficiaries able to finance the firms mostly oriented to perform R&D additionality (*good selection*).

Although our model does not directly describe the agency selection process, some insights of it can be accounted by the "persistency analysis" of the game. Let us address this point by explaining first the way A_t is modelled.

A_t is assumed to follow a two-state Markov Chain with persistency parameter ρ. The two states are "+1" and "-1". When A_t assumes value +1, the effect of the subsidy on firm R&D is positive and "additionality" occurs; vice versa, when A_t assumes value -1, a crowding-out effect of the subsidy on R&D appears. In short, A_t controls for the occurrence of positive/negative effect of subsidy on optimal firm R&D costs.

At heart of the Markov process governing A_t there is the form of the matrix of "transition probabilities" (TP) across states, that outlines the degree of persistency of the process. Indeed, the stochastic behaviour of A_t is governed by movements from "+1" and "-1" and is guided by this transition matrix:

$$\mathbf{P} = \begin{pmatrix} P_{+1,+1} & P_{+1,-1} \\ P_{-1,+1} & P_{-1,-1} \end{pmatrix}$$

where P_{ii} is defined as the probability of A_t to remain in state i in t+1 given it was in state i in t and, accordingly, P_{ij} is the probability of A_t to pass to state j in t+1 given it was in state i in t. It goes without saying that, in our case, $i=+1$ and $j=-1$. Observe finally that $P_{+1,+1}+ P_{+1,-1}= P_{-1,+1}+ P_{-1,-1}=0$ as the process is constrained to be in only one state each time.

A simple but effective way to parametrizing **P** is that of making it function of one single parameter (ρ) as follows (see Davidson and De Jong, 1997):

$$\mathbf{P}=\begin{pmatrix} \frac{1+\rho}{2} & \frac{1-\rho}{2} \\ \frac{1-\rho}{2} & \frac{1+\rho}{2} \end{pmatrix}$$

It is easy to see that $-1 \leq \rho \leq +1$ represents a parameter accounting for the "persistency" of the Markov chain. Indeed three critical values of ρ explain this feature:

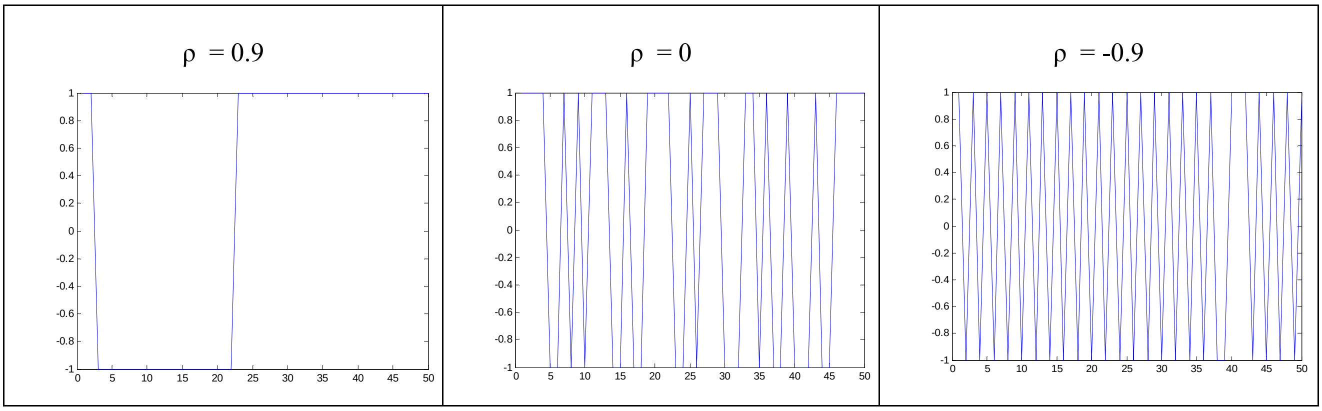
(i) ρ=-1: the lowest level of persistency is reached as the probability of remaining in the same starting state is zero. In this case the process exhibits a continuous movement between -1 and 1;

(ii) ρ=0: the process persistency is higher than before, and a uniform distribution over the events is assumed as the probability of remains into the same state and that of changing state is equal and set to ½; the process exhibits less frequent movements form -1 to +1 (and vice versa) compared to the previous case;

(iii) when ρ=1, finally, the process is fully persistent. It remains in the same starting state along all the simulation period.

Figure 1 shows the representation of the Markov Chain under ρ=-0.9, ρ=0, ρ=0.9.

FIGURE 1. SIMULATION OF THE MARKOV CHAIN A_T UNDER ρ = 0.9, ρ = 0, ρ = -0.9



It is straightforward to see how the behaviour of these processes meets the features outlined above in terms of persistency. Since the persistency of the additionality/crowding-out effect of subsidy on firm R&D is a central issue, the paper aims at comparing the model's outcomes under different degrees of persistency (i.e. different level of ρ). In particular we want to see how subsidy inefficient provision could depend crucially on ρ.

But to what extent is the level of "persistency" linked to the agency "selection process" adopted for choosing financeable R&D projects/firms? What can be approximately assumed is that when the persistency is very low (for example, $\rho=-0.9$) the agency is expected to have chosen firms/projects to finance with the aim of generating a continuous *replacement*. For example, the agency could have wanted to favour a wider access to funds inter-temporally by changing continuously the beneficiaries without taking into account what results have been reached in the past. On the contrary, when the persistency is higher and in particular when ρ is equal to zero, the agency might be thought of as selecting firms *at random*: the probability of staying in the same state and that of changing state is, in this case, exactly the same. When, finally, ρ is positive and close to one, then the agency appears to have given special importance to past selection choices, thus generating a *perpetuation* phenomenon favouring probably the same beneficiaries. In short: (i) *continuous replacement*, (ii) *random assignment* and (ii) *perpetuation* in selection, seem to be three potential situations whose differential effects are worth to assess.

4. THE LOGIC OF THE MODEL

Why should, in our model, the strategic agency-firm interplay generate a suboptimal provision of R&D subsidies? To better answer this question it seems useful to look at the objective function of both the agents involved in the game when, for instance, A_t is equal to 1. In this case the agency payoff increases monotonically as soon as r increases. It means that any higher level of r is strictly preferred to any lower level. By contrast, when s increases it first generates increasing utility and, after a certain threshold, a decreasing pattern. It depends on the balance constrain of the agency that does not have access to unlimited resources. As seen above, it leads to a quadratic form of the agency utility in s (inverted-U shape).

The firms' profit behaves sym-metrically. It increases monotonically as soon as s increases. It means that any higher level of s is strictly preferred to any lower level. By contrast, when r increases it first generates increasing utility and, after a certain threshold, a decreasing pattern since doing r is not costless and a financial constraint, beyond a certain threshold, does hold.

Since we are supposing that agency and firms play a simultaneous game and given the forgone conditions, it is quite easy to show that the "rival" model is characterized by a time moving Cournot-Nash equilibrium that generally is not an optimum according to the "Social-planner" strategy. In order to show this result we present a pivotal *Prisoner's Dilemma-type* example using a simple representation of the game with given payoff.

We suppose that both r and s can assume just two values: high or low. Given the fact that the profit as well as the agency welfare are inverted-U shapes, during the simulation it could happen that on the part of the firm, sometimes a low *r* will be preferred to a high *r* and sometime the opposite might occur. Similarly, on the part of the agency and according to the evolution of the model, sometimes a low *s* will be preferred to a high *s* and sometimes the opposite will occur. Generally, four cases could appear whatever *s* for the firm and *r* for the agency, that is:

Case 1. For the firm *r* low is preferred to *r* high; for the agency *s* low is preferred to *s* high;

Case 2. For the firm *r* low is preferred to *r* high; for the agency *s* high is preferred to *s* low;

Case 3. For the firm *r* high is preferred to *r* low; for the agency *s* low is preferred to *s* high;

Case 4. For the firm *r* high is preferred to *r* low; for the agency *s* high is preferred to *s* low.

Case 1. Table 1 sets out the form and solution of the game in case 1. Let's start with the agency strategy. Either by choosing a high level of *s* or a lower one, the agency always prefers an higher *r*. Indeed, when *r* is high and *s* is high too the agency gets a utility of 15 against a utility of 5 when *r* is low. When *r* is low performing an higher *s* is more expensive and the agency prefers a lower *s* (with a utility of 10 against 5). The payoff of the firm is symmetric. The firm prefers always a higher level of *s*. When *r* is high it gets a profit of 15 when *s* is high and 5 when *s* is low. Vice versa, when *r* is low. Under these assumptions it is easy to see that the equilibrium of the "rival" model is (*r*-low, *s*-low) while the Social-planner solution, found by maximizing the sum of the two payoffs, is (*r*-high; *s*-high) where this sum is 30 against 20 in the Nash solution.

TABLE 1. GAME REPRESENTATION UNDER CASE 1

		Agency	
		S high	S low
Firm	R high	15;15	5;20*
	R low	20*;5	10*;10*

TABLE 2. GAME REPRESENTATION UNDER CASE 2

		Agency	
		S high	S low
Firm	R high	15;20*	5;15
	R low	20*;10*	10*;5

TABLE 3. GAME REPRESENTATION UNDER CASE 3

		Agency	
		S high	S low
Firm	R high	20*;15	10*;20*
	R low	15;5	5;10*

TABLE 4. GAME REPRESENTATION UNDER CASE 4

		Agency	
		S high	S low
Firm	R high	20*;20*	10*;15
	R low	15;10*	5;5

Case 2. The firm prefers *r*-low to *r*-high whatever *s*, but the agency prefers *s*-high to *s*-low. The game form is visible in table 2. It is straightforward to observe that the new equilibrium is (*r*-low; *s*-high), while the optimal value is again (*r* -high; *s*-high).

Case 3. Table 3 shows the game outcome in case 3. For the firm now *r*-high is preferred to *r*-low whatever the level of *s*. But for the agency *s*-low remains preferred to *s*-high whatever the level of *r*. It is easy to see that the new Nash equilibrium is (*r*-high; *s*-low) while in (*r*-high; *s*-high) the sum of utilities is again greater.

Case 4. Whatever *s*, for the firm *r*-high is preferred to *r*-low and whatever *r* for the agency *s*-high is preferred to *s*-low. In this case the Nash equilibrium of the game is equal to the optimal one (*r*-high; *s*-high). See table 4.

According to this example, it is quite easy to see how the externality generated by the rival strategic interaction leads to an underprovided level of both *r* and *s*, while the Social-planner behaviour, i.e. the cooperative strategy, always leads to an higher level of *s* and *r*. The Social-planner "internalizes the externality generated by the firm-agency rival behaviour", inducing a better systemic performance (as it occurs in the case of a generic "positive externality").

Observe that the Nash equilibrium of case 4 is optimal as it is equal to that reached by the Social-planner. It means that – along the time pattern - the sum of the two agents' objective function under rivalry is always lower than the social welfare function under cooperation, although sometimes it could be equal. In other words, the cooperative equilibrium is an upper bound of the rival one. Similar conclusions can be found in the case in which A_t takes a negative (rather than a positive) value (-1), in what case the subsidy generates "negative" rather than "positive" externalities on firms' profit.

5. SIMULATION RESULTS

In order to get simulative results from the model we need to parameterize the model, by choosing parameters' level and the starting point of our simulations. Parameters have been chosen to get reliable and coherent values of the variables considered (to avoid, for example, negative sign for variables that ought to be positive, and so on). Furthermore, as the "ratio of R to S" is the central variable of our analysis, we set to start our simulations at a level or R/S close to that found in real data (about 40%) as shown in table 5, where data are drawn from the Unicredit/Capitalia survey on Italian manufacturing firms in the period 1998-2001. Meaning and level of the various parameters are set out in table 6.

TABLE 5. SOME SAMPLE DESCRIPTIVE STATISTICS

Number of observations	3452
Share of total R&D expenditure by financial source (supported firms):	
Self-financing	53 %
New equity	1 %
Debt	6 %
Subsidy	39 %

TABLE 6. MEANING AND VALUES OF PARAMETERS

ϕ_0	fi0	25	Scale parameter of the R&D Marginal Rate of Return (MRR)
ϕ_1	fi1	5	Slope parameter of the R&D Marginal Rate of Return (MRR)
μ	mu	1.5	Fixed cost parameter of the R&D Marginal Capital Costs (MCC)
β	beta	8	Subsidy effect parameter of R&D Marginal Capital Costs (MCC)
γ	gamma	1	Knowledge stock effect parameter of R&D Marginal Capital Costs (MCC)
δ	delta	0.15	Depreciation rate of knowledge stock
ψ	psi	20	Parameter governing the cost of providing subsidies for the agency
β_0	beta0	0.96	Agency inter-temporal discount rate
ρ	rho	-0.9, -0.5, 0, 0.5, 0.9	Persistency parameter (ranging between -1 and 1)

Figure 2 set out our model's simulative results got by comparing rivalry and cooperative outcomes of a Monte Carlo simulation with 10,000 replications with a ρ set up equal to 0.5 over a time span of 50 periods. The observed patterns are average values over these 10,000 runs. This simulation of the model shows very interesting results. First, both the level of R&D expenditure and subsidy is found to be severely undersized, as in the rival case they both are lower than in the Social-planner's case. It emphasizes not only that the subsidy is unable to generate the optimal level of R&D, but that this phenomenon is due primarily to the fact that the level of the subsidy provided by the agency is too much low compared to the socially optimal amount. Consequen-tly, the ratio S/R is undersized as the optimal average level over the 50 periods simulation should be (on average) about 50% while it is only about

40% in the rival case: it means that the agency should provide about a 23% higher level of the R/S ratio currently provided if it wants to achieve the social optimum. This is the main policy consideration offered by this model. The results on the agents' payoffs are also worth to stress: rival situations tend to advantage more the agency than the firm, and the optimal level reached by the Social-planner tends to reduce the payoff of the agency in favour of firm profits. Also in terms of overall welfare, as was expected, results show the dominance of the Social-planner outcome over the rival one. In what follows we sum up these results:

Conclusion 1. The relative quota of S to R (i.e., the ratio S/R) is undersized in the rival compared to the Social-planner model. It means that an increasing level of S/R is needed to reach welfare-superior results.

Conclusion 2. The rivalry strategy generates distortions that favor the agency compared to firms. This distortion can be healed by an increasing S/R ratio.

Let us now turn to the results under different path-dependence assumptions. Table 7 reports the results for five levels of ρ (-0.9, -0.5, 0, 0.5, 0.9) on various model endogenous variables. The values reported in this table are interpreted as "distortions" (or "biases") of the rival outcome when compared to the Social-planner benchmark, that is:

$$100 \cdot \frac{Y_c - Y_r}{Y_r}$$

where Y_c is the Social-planner outcome on variable Y and Y_r the generic rival outcome. [see Table 7].

Generally speaking the 50 periods simulations put into evidence a quite clear regularity: as long as we pass from a very low persistency of A_t (-0.9) to the highest one (+0.9) we get an increasing level of the "rival inefficiency" (or "welfare-bias") in terms of S, R and S/R, but with a parallel increase of the variance of results over the 10,000 replications considered. For example: the R/S ratio bias when ρ is equal to -0.9 is about 4.6% that is substantially lower than that of 32.6% reached when ρ is equal to 0.9; nevertheless, the coefficient of variation in the latter case (1,309) is about seven time greater than in the former case (194). It means that when the persistency of the additionality/ crowding-out effect is weaker (stronger), the potential welfare-bias is lower (higher), but with a variance that is generally higher (lower). It means that a sort of trade-off between the reduction of the bias and the level of variance (risk) when moving from a lower to a higher persistency does arise. Similar results can be drawn by looking at what happens in terms of the level of S and R. Overall, it leads to the following conclusion:

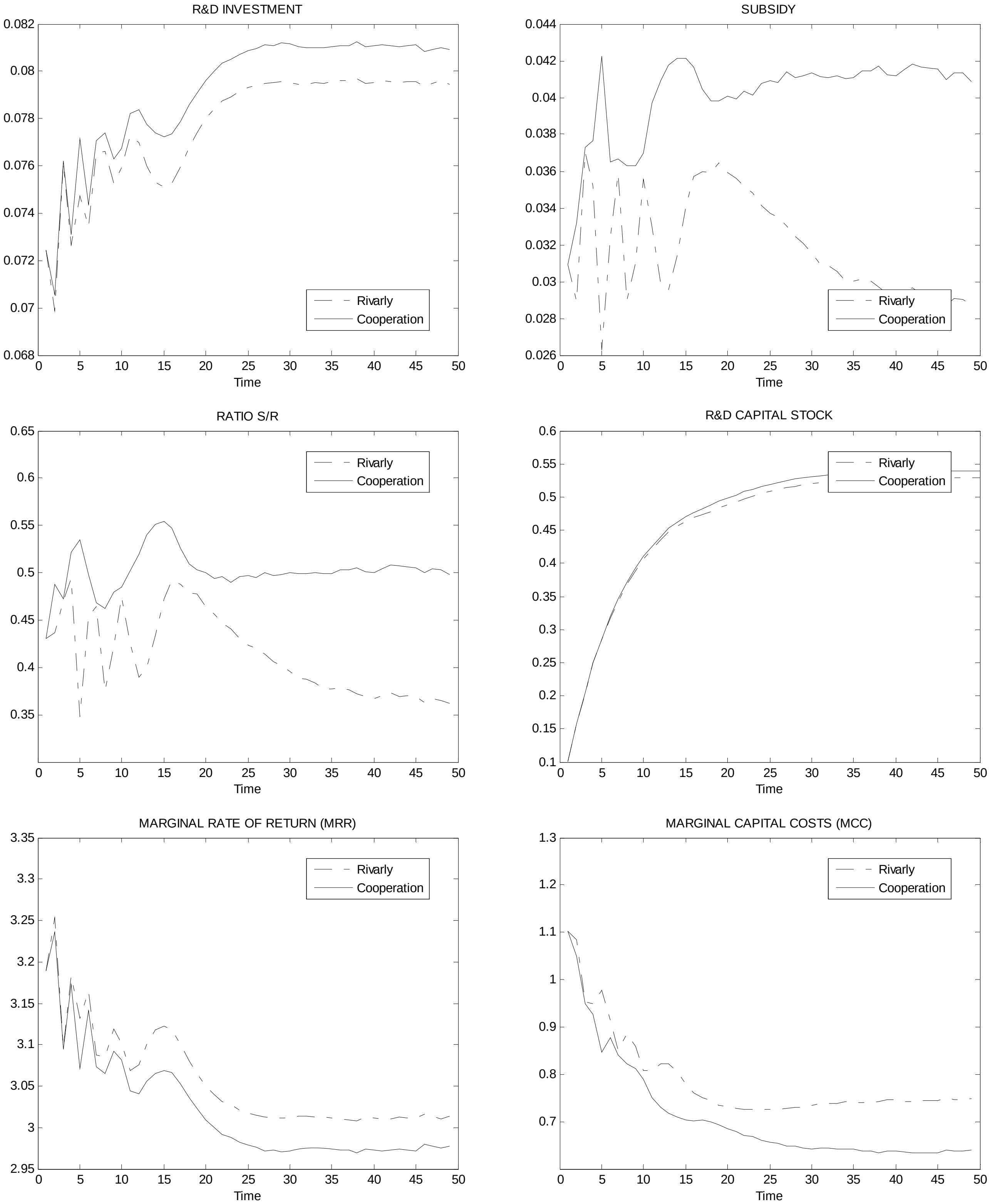
Conclusion 3. In passing from less persistent to more persistent R&D additionality/crowding-out effect the lower the bias, the greater the variance is and vice versa, so that a dominant choice of ρ does not emerge.

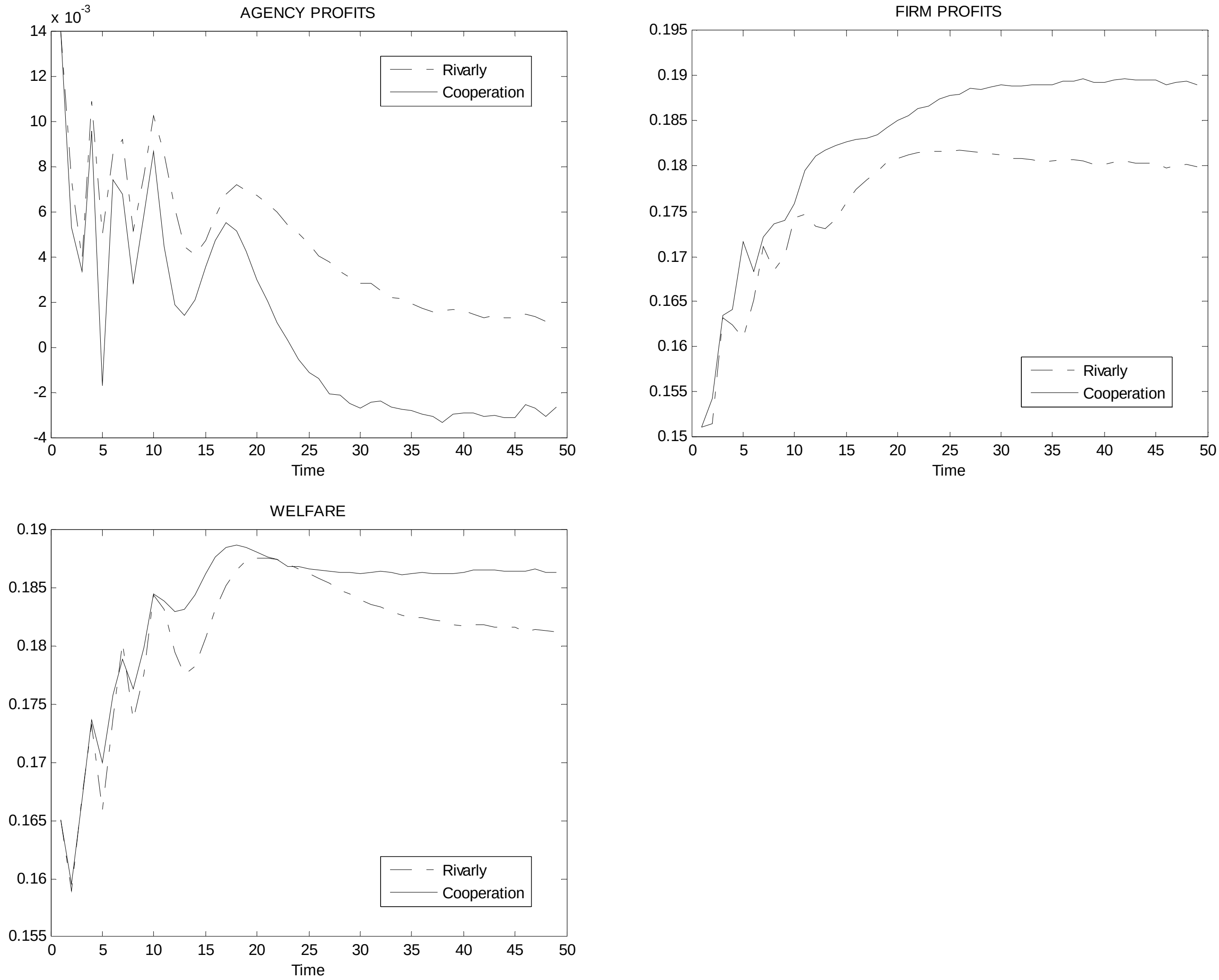
TABLE 7. SIMULATION RESULTS OF MODEL ENDOGENOUS VARIABLE UNDER DIFFERENT LEVELS OF ρ

	1 Subsidy	2 Stock of knowledge	3 Marginal capital costs (MCC)	4 Marginal rate of return (MRR)	5 Agency profit	6 Firm profit	7 Ratio S/R	8 R&D expenditure	9 Welfare	Mean
					ρ = -0.9					
Mean	12.36	3.21	-5.61	-2.07	-98.90	2.52	4.61	3.36	0.64	-8.88
St. Err.	72.60	0.87	9.56	1.13	323.54	4.58	60.31	1.88	7.03	53.50
CV	587.40	27.08	170.37	54.76	327.13	181.92	1309.69	56.12	1104.75	424.36
					ρ = -0.5					
Mean	8.22	1.89	-4.67	-1.25	-24.77	1.89	4.02	2.01	0.43	-1.36
St. Err.	22.43	0.51	4.87	0.70	133.16	2.45	18.46	1.25	1.16	20.55
CV	272.99	26.69	104.14	55.95	537.48	129.36	459.53	62.43	273.17	213.53
					ρ = 0					
Mean	58.21	1.98	-14.17	-1.44	-236.63	5.18	34.83	2.26	2.54	-16.36
St. Err.	68.96	0.79	8.87	0.57	3661.68	3.02	24.50	0.89	2.05	419.04
CV	118.46	40.01	62.58	39.36	1547.41	58.39	70.35	39.21	80.63	228.49
					ρ = 0.5					
Mean	27.08	1.64	-9.99	-1.17	-151.98	3.65	22.98	1.82	1.51	-11.61
St. Err.	14.33	0.60	4.47	0.39	119.27	1.54	13.35	0.61	1.13	17.30
CV	52.92	36.35	44.76	33.14	78.48	42.13	58.10	33.52	74.70	50.46
					ρ = 0.9					
Mean	39.73	2.15	-10.83	-1.49	-62.55	4.19	32.57	2.33	1.69	0.86
St. Err.	75.44	0.77	6.44	0.99	151.19	3.51	63.18	1.66	2.28	33.94
CV	189.89	35.67	59.46	66.42	241.70	83.79	193.98	71.33	135.42	119.74

NOTE: CV = |St. Err./Mean*100|. Reference variable: $100*(Y_c - Y_r)/Y_r$ where Y_c = cooperative outcome, Y_r = rival outcome. ρ = degree of persistency in additionality/crowding-out effect.

FIGURE 2. MODEL SIMULATIONS WITH $\rho = 0.5$





As for the alleged optimal level of ρ, the only aspect that can be stressed is the good compromise represented by the case in which of ρ is equal to 0.5, where the welfare-bias is not too harsh and the variance is at the same time quite small.

What policy message can we draw from this analysis? Of course there is not a "direct" mechanism to control the level of persistency of the additionality/ crowding-out effect. In this sense there is not a specific policy instrument on the part of the government. What less ambitiously our result aim at suggesting is to take this "persistency behaviour" as a sort of "cautionary note" when providing R&D subsidies to private corporations via public agencies. Of course, the "selection into the R&D supporting program" mechanism can roughly give some direction to the process, although limited and approximated. In this sense, a selection mechanism aimed at awarding quite recurrently the same subjects could probably encourage some persistency thus producing an increasing likelihood of stronger biases; but also a continuous replacement, although promoting a little less persistency, has its drawback as it renders - on average - the outcomes less biased even though with a very higher level of results' variability. Our model seems to suggest to be not too much extreme in positioning the selection mechanism between perpetuation on one hand and continuous replacement on the other, as both seem to engender problems. It goes without saying that these results also depend crucially on the "quality" (i.e., degree of success/failure) of firm R&D projects that, together with the selection mechanism, drives the realization of A_t; it is for this reason that our conclusions have to be taken only as indicative suggestions and not as prescriptive policy recommendations.

CONCLUSIONS

The simulative model presented in this paper shows quite clearly to which extent the level of R&D subsidies chosen by an inter-temporal maximising funding agency could be severely undersized. This is the main result of the time-moving Cournot-Nash equilibrium generated by the agency-firm game. The model predicts under this assumption that both private R&D and R&D support are too low compared to the social optimum, thus generating a "policy failure" that previous studies dealing with this subject seemed to have somewhat overlooked.

As for more detailed results, after running 10,000 simulations of the rival and cooperative model under a "medium" level of persistency (ρ=0.5) over 50 periods we get that, on average, the "rival" strategy sets out a subsidy-R&D ratio about 10% lower than the "cooperative" (that is, the "optimal") one: the share of R&D subsidy on total R&D proves thus to be undersized with respect to its optimal level. This result is confirmed along various values assumed by the persistency parameter of the Markov chain. Interestingly, we also find that the "welfare distortions" due to strategic inter-action are lower when persistency is lower and vice versa, although the variability of this result is higher in the case of low persistency than in the opposite case. It means that a public actor who wants to reduce welfare distortions has to cope with a sort of trade-off between the degree of distortion and its variability. In this sense, according to our results, a dominant level of the persistency parameter does not arise.

According to our findings two issues seem to be important for the management of R&D funding policies: (i) all the elements favouring greater cohesion and collaboration between agency and firm objectives (i.e., less rival policy settings) can help to move the level of current R&D support towards its social opti-mum[2]; (ii) the selection mechanism operated by the public agency, needs to be not too much extreme between perpetuation (when awarding the same subjects over time) on one hand and continuous replacement (when changing financed firms continuously) on the other, as both seem to generated suboptimal situations.

[2] As widely recognized, for example, a larger firm project information desclusure could be a good strategy for promoting greater cooperation, as well as better comunication and agreements between the public agency and the firm on sharing and exploiting project oucomes.

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