

Optimal technology policy: subsidies versus monitoring

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Abstract

We analyze the optimal technology policy to solve a free-riding problem between the members of a RJV. We assume that when intervening the Government suffers an additional adverse selection problem because it is not able to distinguish the value of the potential innovation. Although subsidies and monitoring may be equivalent policy tools to solve firms' free-riding problem, they imply different social losses if the Government is not able to perfectly distinguish the value of the potential innovation. The supremacy of monitoring tools over subsidies is proved to depend on which type of information the Government is able to obtain about firms' R&D performance.

Keywords: RJV, moral hazard, adverse selection, subsidies, monitoring.

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1 Introduction

There is strong theoretical base and empirical evidence that the social benefit from R&D may be greater than the benefit available to the innovator. A variety of strategic and opportunistic reasons may cause a spread between private and social incentives to conduct R&D. One possible source of divergence is the existence of technological spillovers since firms conducting R&D do not take into account the positive effects that their own R&D investments have on the rest of the economy. As a result, the private investment in R&D is lower than the socially optimal.¹ Another reason for the gap between social and private returns to R&D is related with the problems of opportunism and asymmetric information faced by firms in collaborative projects, since important inputs of joint research activity cannot be contractible.² We focus on this latter issue. We consider a collaborative project that requires the complementary skills of two risk-neutral firms. Research efforts are not verifiable and privately costly so firms have incentives to free-ride and the final provision of R&D is lower than the socially optimal (double-sided moral hazard problem).

The difference between private and social returns to R&D investments constitutes one of the main justifications for public intervention. Technology policy makers have a number of means of encouraging such investment, including subsidies and monitoring processes. Subsidized cooperative R&D projects have become an important tool of the industrial policy in the United States, Japan and Europe. Some examples of subsidized research corporations in the United States are the Microelectronics and Computer Consortium (MCC) or the ones sponsored by the Semiconductors Manufacturing Technology (SEMATECH). European governments have also agreed in sponsoring collaborative research through programs such as the European Research Coordination Agency (EUREKA), European Strategic Program for R&D in Information Technology (ESPRIT) or the Base Research in Industrial Technology for Europe (BRITE). Furthermore, Tripsas, Schrader and Sobrero (1995) point out that 80% of the research loans made by the Japanese Government are devoted to joint projects. Despite the extended application of subsidies as a policy tool some governments may prefer monitoring mechanisms in which more public control is combined with money incentives. Clear examples are the MITI in Japan, in which the Government assumes the role of an effective coordinator, or the Società di Ricerca Program in Italy, in which a manager is selected to supervise the execution of individual projects and coordinate the ongoing efforts of participating firms. Moreover, the Advanced Technology Program

¹For a related literature see, for example, D'Aspremont and Jacquemin (1988), Kamien, Muller and Zang (1992) or Kesteloot and Veugelers (1995).

²See, for example, Choi (1992) or Pérez-Castrillo and Sandonís (1996).

(ATP) in the United States combines initial subsidies with some monitoring tools, providing guidance in putting together a RJV and periodical evaluations of firms' R&D performance.

The literature examining R&D subsidies is rather sparse despite their extensive use as a policy tool.³ Unfortunately, a policy relying on subsidies to correct R&D market failures has potentially serious shortcomings. Katz and Ordover (1990) argue that such policies may be subject to severe asymmetric information problems: firms reporting higher R&D expenditures or better potential innovations in order to collect higher subsidies.⁴ As a result, some authors look at monitoring policies as a possible alternative. In particular, Tripsas, Schrader and Sobrero (1995) argue in their study of the Italian Società di Ricerca program that the Government may discourage opportunistic behavior on the part of RJV participants through improved monitoring (by formal auditing of the activities of the private sector members), through an ability to threaten reprisal (either explicitly if the RJV gives the Federal laboratory the legal power to discipline deviators or implicitly if the Federal laboratory is willing to exclude noncompliant firms from future collaborative activities), or through facilitating longer term relationships. However, there is not a general agreement about the effectiveness of any of these policy tools over the another to encourage R&D investments.

We analyze the optimal technology policy in a context of asymmetric information. A public regulator will try to solve firms' free-riding problems and restore their incentives to conduct R&D. However, it will be assumed that the regulator does not know precisely how much money firms will be able to obtain through patents. Therefore, the Government trying to solve the underprovision of efforts faces an additional adverse selection problem, given its inability to distinguish the value of the potential innovation.

There exist in the literature some papers designing optimal mechanisms to implement socially optimal efforts in the presence of both moral hazard and adverse selection problems (see Picard and Rey, 1990, or McAfee and McMillan, 1991). They find optimal mechanisms such that imperfect observability of the contributions entails no additional welfare loss compared to the pure adverse selection case. Although these papers are important contributions from the theoretical point of view, they propose rather complex mechanisms hard to be empirically implemented by a social planner. The purpose of this paper is not the design of such theoretical mechanisms rarely applied by governments but the analysis and comparison of two extensively

³See, for example, Spencer and Brander (1983), Pérez-Castrillo and Verdier (1993), Romano (1989), or Stenbacka and Tombak (1998)

⁴Indeed, Brown (1984) found that in response to the Economic Recovery Act of 1981 the increases in R&D expenditures reported with tax purposes greatly exceeded the growth in spending reported in *Business Week's* survey of R&D expenditures.

used policy tools: subsidies and monitoring.

Two possible monitoring systems are considered. In the first one, all the Government is able to verify is whether a firm has succeed or not in fulfilling its part of the project but nothing about real research efforts. This type of monitoring is more likely to be applied in high technology industries, in which verifying real efforts might become extremely hard. In the second monitoring system, the Government manages to verify the real research effort exerted by each of the participating firms. We consider as a benchmark a situation in which subsidies and both monitoring systems are equivalent to increase firms' incentives to conduct R&D if the Government is able to perfectly distinguish the value of the potential innovation. However, different policies induce different social losses if an additional adverse selection problem arises. Subsidies and monitoring are no longer equivalent to solve firms' moral hazard problem when the regulator faces an additional problem of adverse selection. It is proved that if only partial results can be observable, it is better to use subsidies rather than monitoring. However, if research efforts become verifiable monitoring is socially dominant. Therefore, the superiority of monitoring tools over subsidies depends on which type of information the Government is able to obtain about firms' R&D performance. It is also discussed the optimal combination of subsidies and monitoring if these policy tools are not ex-ante equivalent. On the one hand, if partial results monitoring is cheaper than subsidies, low value innovators should be monitored more intensively than high value innovators, while high value innovators should receive higher subsidies. On the other hand, if subsidies are less costly than research effort monitoring, it is optimal to monitor more the high value innovators and grant higher subsidies to low value ones.

The paper is organized as follows. Section 2 presents the model, firms' free-riding problem and the additional adverse selection problem for the regulator. In section 3, we analyze the welfare losses induced by each policy tool when the Government is unable to distinguish the type of the project and discuss the optimal policy choice. Section 4 concludes.

2 The model

Let us consider two risk neutral firms with complementary research capabilities that decide to start a collaborative project. For the sake of simplicity, we consider that each firm has a comparative advantage in a part of the project so research is divided in two different tasks and firms work in separated laboratories. Once both firms have successfully completed its corresponding task, results are combined to obtain an innovation of value $V \in \{\bar{V}, \underline{V}\}$ with $\bar{V} > \underline{V}$. The value of the innovation is common knowledge for both firms at the beginning of the collaborative agreement. If one firm fails in fulfilling its part of the project, the innovation

is not obtained.⁵ We assume it could be too costly for a firm to verify that it has succeeded in solving its part but its partner has not, that is, it is not possible for firms to sign contracts based on individual success.

Even if the innovation is not finally achieved, a successful firm learns new technical methods and procedures that may be applied in future research. We assume firms obtain some particular utility w if they manage to successfully finish their task, independently of whether its partner has succeeded or not.⁶ The private benefit w can be interpreted as the value of the know-how firms learn when fulfilling their task and it is assumed to be strictly smaller than the innovation value, $\underline{V} > w > 0$. This assumption ensures that we obtain an interior solution both in the cooperative and noncooperative game without introducing complex functional forms.

Firms decide about the amount of real R&D investments, called efforts, which affect the success of their part of the project. For the sake of simplicity, assume that the effort e_i that firm i exerts in fulfilling its task represents the probability of it being successful, which is independent of the probability of success of its partner. R&D efforts are not observable and hence not contractible. The cost of research effort is assumed to be quadratic, implying the existence of decreasing returns to R&D expenditures.⁷ In particular, the cost of firm i 's R&D investment is assumed to be $\theta e_i^2/2$, where θ is inversely related to the efficiency of firms' innovation process. Given our interpretation of R&D efforts as the probabilities of success, assuming $\theta > 2\bar{V}$ is sufficient to guarantee that equilibrium efforts belong to the interval $[0, 1]$.

The timing of the game is as follows: First, Nature determines whether the project has a high value \bar{V} or a low value \underline{V} . The final innovation value will strongly depend on the characteristics of the market in which it will be introduced such as the level of demand and competition, innovator's ability to price discriminate or degree of technological spillovers. The realization of the innovation value is perfectly observed by both firms. Secondly, firms specify the collaborative agreement including the division of tasks and share of profits α_i . Each firm is responsible just for a part of the project and it simultaneously and noncooperatively undertakes

⁵These kind of collaborative projects are quite common in high technology industries. For example, Sandonís (1993) points out that, when developing the aircraft Boeing 767, a consortium of Japanese firms made the fuselage, Aeritalia designed and produced the tail and the rudder and Boeing took charge of the wings, cabin and final assembling. Another example is the production of the "V. 2500 turbofan jet engine" motor by Pratt & Whitney and Rolls Royce with a clear division of the project based on the comparative advantage of each firm.

⁶Dasgupta and Tao (1998) also consider that a collaborative project may generate some exclusive benefits for the two firms but they only take them into account if firms have succeeded in developing the targeted products.

⁷The assumption of quadratic cost for R&D investments is usually applied in the cooperative and noncooperative R&D literature. Some examples are Beath, Poyago-Theotoky and Ulph (1998), D'Aspremont and Jacquemin (1988), Kesteloot and Veugelers (1995) and Sandonís (1993).

an unobservable effort that is privately costly. Finally, firms obtain their payoffs: If firm i is successful in performing its assignment, it obtains w if its partner fails and $(\alpha_i V + w)$ if its partner succeeds. If firm i does not succeed, it receives nothing, independently of whether its partner has succeeded or not. This assumption is justified by the fact that firms carry out their research in separate laboratories. The expected profit for firm i is given by the following expression:

$$\Pi_i(e_i, e_j, \alpha_i) = e_i e_j \alpha_i V + e_i w - \theta \frac{e_i^2}{2}, \quad (1)$$

with $V \in \{\bar{V}, \underline{V}\}$, $\alpha_i \in [0, 1 - \alpha_j]$, $i \neq j$ and $i, j = 1, 2$.

2.1 Equilibrium in efforts

Once the project has been divided in two independent tasks and the sharing rule has been fixed, RJV participants are assumed to behave noncooperatively. Firm i maximizes the expected profits given by expression (1), choosing its research effort while taking its partner's effort as given. The non-cooperative Nash equilibrium efforts are given by:

$$e_i^{nc}(V) = \frac{w\theta + \alpha_i w V}{\theta^2 - \alpha_i(1 - \alpha_i)V^2} \text{ with } V \in \{\bar{V}, \underline{V}\}, i \neq j \text{ and } i, j = 1, 2.$$

When acting in a noncooperative way, firms only take into account their private benefits disregarding that their research decisions will have an effect in its partner's profits. As a result, the choice of R&D investments may not be optimal from the social point of view. We will consider as the first-best equilibrium the research efforts resulting from internalizing the effects that a firm may generate to the another, that is, from cooperating in the choice of efforts. As defined before, the first-best equilibrium R&D efforts for every project $V \in \{\bar{V}, \underline{V}\}$ are the solution of the following maximization problem:

$$\underset{e_1, e_2}{Max} \left\{ e_1 e_2 V + e_1 w + e_2 w - \theta \frac{e_1^2}{2} - \theta \frac{e_2^2}{2} \right\},$$

that is $e_i^*(V) = \frac{w(\theta+V)}{\theta^2-V^2}$ with $i \neq j$ and $i, j = 1, 2$.

Comparing the cooperative and noncooperative approach, it is straightforward to show that the resulting equilibrium efforts will be different, no matter firms' agreement on how to share innovating profits. This is a well-known result in team theory due to Holmstrom (1982) and it is formally stated in the following lemma.⁸

⁸See Gandal and Scotchmer (1993), Morasch(1995), Radner (1991) and Vislie (1994) for exceptions to this result. These exceptions do not apply here.

Lemma 1 *There does not exist any sharing rule $\alpha_i \in [0, 1 - \alpha_j]$ such that for every firm i of type V the non-cooperative Nash equilibrium effort $e_i^{nc}(V)$ coincides with its first-best $e_i^*(V)$.*

Since both firms are symmetric, it is optimal to equally split innovation profits and the noncooperative solution yields to lower research effort than the first-best optimum. Given that firms equally share the innovation profits but efforts are privately costly and not verifiable, RJV participants have incentives to free-ride. The problems of opportunism and asymmetric information reduce the incentives to exert research effort and lead to an insufficient investment in R&D (double-sided moral hazard problem). This is formally summarized in Lemma 2.

Lemma 2 *The optimal sharing rule is $\alpha_i = \frac{1}{2}$, $i \neq j$ and $i, j = 1, 2$. Moreover, for every firm of type V the noncooperative Nash equilibrium effort $e^{nc}(V)$ is strictly smaller than its first-best $e^*(V)$.*

A benevolent social planner would surely be interested in solving firms' coordination problems and restore their incentives to conduct R&D. However, the Government is in general less informed about market conditions than firms and it will be extremely hard for it to distinguish whether the innovation value is high or low. All the regulator knows is the proportion $p \in [0, 1]$ of high value innovations. The Government trying to solve the moral hazard problem within a RJV will run into an additional problem of adverse selection, because of its inability to distinguish the type of the project and the potential strategic behavior of innovators. We will show in next section that the choice of the optimal policy is not trivial at all.

3 Policy tools

Several policies may be used to alleviate firms' incentives to free ride and encourage R&D investment, such as subsidies or monitoring. The literature examining R&D subsidies is rather sparse despite their extensive use as a policy tool and there is still not a general agreement about its effectiveness to correct R&D market failures. Instead some economists claim that a monitoring policy could be more appropriate to encourage R&D investments since it combines money incentives with public control on firms' activities. In this section, we will consider as benchmark a situation in which both policy tools are equivalent to increase firms' incentives to cooperate. This result agrees with Holmstrom (1982) and McAfee and McMillan (1991) in maintaining that in presence of subsidies, monitoring is not needed to reduce the incentives to free-ride of the members of a team.

Although subsidies and monitoring may be equivalent policy tools to mitigate the moral hazard problem, they will not be longer equivalent if an adverse selection problem is added. If

the Government is unable to identify the type of the project, it will have to look for the best way to, not only encourage firms to cooperate, but also discourage firms to lie about the value of their future innovation. Therefore the choice of the best way of intervention becomes more complex.

There are, roughly, two essential ways to give subsidies. One is through cost subsidies when the Government pays some of the expenditures undertaken during the innovation process. The other is through the patent system and consists of granting an additional prize to the innovator. Pérez-Castrillo and Verdier (1993) proved that under severe moral hazard problems it is not optimal for technology policy makers to use cost subsidies. Probably that is why the patent subsidy system has been largely employed in United States and Germany in high technology industries, such as the biotechnology sector. (See Adelberger (1999) and Abramson *et al.* (1997)). Since as a benchmark we are considering equivalent policy tools to solve a moral hazard problem, we will focus on patent subsidies.

An alternative technology policy to alleviate the problem of free-riding consists of monitoring firms' actions. Governments embody unique human and technical capital that is rarely available in the private sector (Leyden and Link, 1999) and thus they may be able to monitor firms at a lower cost than RJV participants. By monitoring we will mean all those mechanisms used by the social planner in order to obtain information about firms' research effort and decrease their incentives to behave in an opportunistic way. The Government sends some research experts to firms' laboratories to judge and evaluate their R&D performance.⁹ These Federal experts, in their role as an "honest broker", can strongly discourage firms' strategic behavior and increase their incentives to innovate.¹⁰ The monitoring mechanism includes direct supervision and money incentives. Depending on the efficacy of the evaluating process, we will distinguish two possible cases. In the first case, Federal advisers are only able to identify whether a firm has individually succeeded or not but they learn nothing about research efforts. We refer to this as partial results monitoring. In the second case, scientific experts, after an arduous and costly auditing process, are able to verify the real effort exerted by each RJV member when fulfilling their corresponding task. We refer to this as research efforts monitoring.

We will assume, as it is usual in regulation models (Laffont and Tirole, 1993), that public

⁹Even in the case that RJV participants own the human and technical capital necessary to monitor their partners, they are not likely to be allowed to do so, since other strategic information may be revealed during the evaluating processes.

¹⁰Leyden and Link (1999) argue that it is precisely this role of an "honest broker" what induces some RJV to invite a public partner to participate. In particular, they provide empirical evidence that larger collaborative research relationships have a greater incentive to include a Federal laboratory as a member than smaller ones, since free-riding problems become significantly more important in large RJV.

funds are obtained through distortionary taxation. The distortion costs λ are identical for all means of intervention. In all cases, firms behave noncooperatively so socially optimal efforts must be implemented as a noncooperative Nash equilibrium. We will prove that regulator's inability to identify each type of project affects the optimal results attained by each policy tool in a different manner and the choice of the optimal technology policy is not trivial.

3.1 Patent subsidies

Let S_i represent the patent subsidy received by firm i , that is, the added prize that it will obtain once the innovation is discovered. Since we are considering symmetric firms, both RJV members receive the same subsidy in case of joint success, that is $S_1 = S_2 = S$. However, the level of the subsidy may differ for different types of projects. Let us denote by \bar{S} and \underline{S} the patent subsidies received by each of the participating firms of a high value and low value project, respectively.

If the Government were able to perfectly distinguish each type of project and distortionary costs were not excessive, it would be socially optimal to spend more resources in the high value innovation project than in the low one. Obviously, if the distortionary cost of public funds were too high it would be better not to intervene or, in some cases, to subsidize just the high value project. On the other hand, if there were not distortion costs for public funds, $\lambda = 0$, and the Government could anticipate the innovation value of every project, first-best equilibrium efforts could be attained in both type of projects. This is no longer true if the regulator faces an adverse selection problem as it is stated in the following proposition.

Proposition 1 *If the Government is unable to distinguish the type of the project, the optimal menu of subsidies $\{\bar{S}; \underline{S}\}$ satisfies the following properties:*

- a) *The optimal subsidy coincides for both types of projects, that is $\bar{S} = \underline{S} = \tilde{S}$.*
- b) *There exists an upper bound for the distortion cost λ^S such that the optimal subsidy is zero above it. Below λ^S , the optimal subsidy \tilde{S} is a strictly decreasing and convex function of λ . Moreover, below λ^S the maximum social benefit $W(\tilde{S}, \bar{V}, \underline{V})$ is also a strictly decreasing and convex function of λ .*
- c) *First-best equilibrium effort is never attained for the high value project while the effort implemented for the low value project may be excessive.*

We know that it is socially optimal to devote more public funds to a high value innovation project than to a low one. However, if the Government is unable to distinguish the type of the project, low value innovators have few incentives to reveal their true type and the policy maker

will be forced to establish the same subsidy for both types of projects. Moreover, Proposition 1 shows that the first-best equilibrium effort is never obtained for the high value projects while R&D investment may be higher than the socially optimal for the low ones. The main results of Proposition 1 are summarized in Figure 1. The social benefit for different values of the distortion cost λ is plotted. As it is shown in the figure, the social benefit is strictly concave in S and strictly decreasing in λ . The darker curve corresponds to the maximum social benefit for every possible value of the distortion cost, a strictly decreasing and convex function of λ . If the distortionary cost is higher than λ^S , it is optimal for the Government not to intervene and the maximum social benefit is just the one without intervention, $W(0, \bar{V}, \underline{V})$. Below λ^S , the optimal subsidy is always below $\bar{V}/2$ (so first-best effort is never attained for high value projects) while it is higher than $\underline{V}/2$ if the distortion cost is below λ_S (so the effort implemented for the low value project turns out to be excessive).

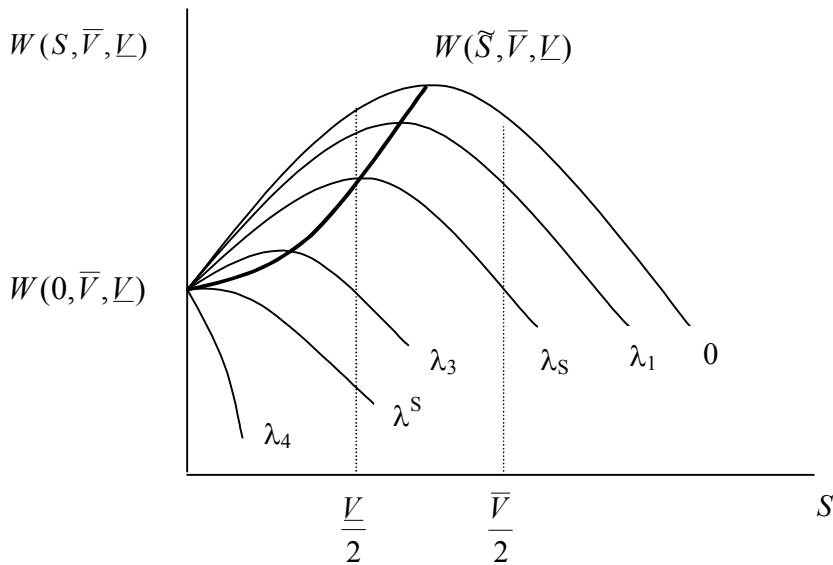


Figure 1: Optimal subsidy if the Government cannot distinguish the type of the project, with

$$0 < \lambda_1 < \lambda_S < \lambda_3 < \lambda^S < \lambda_4.$$

3.1.1 Partial results monitoring

In this case, Federal experts are sent to each RJV member's laboratory in order to gather any kind of information about firms' research effort and evaluate their innovation process. However, there are many situations in which it may become especially difficult for experts to verify real research efforts. For example, it could be really hard to verify whether researchers are thinking of how to go through the project or how to organize their weekend. In this subsection we

assume that experts are unable to verify efforts but they have the specialized knowledge and advanced methods to unequivocally identify partial success in a costless way.¹¹ Let m_i be the monetary transfer that the regulator makes to firm i if it is individually successful, independently of whether its partner has succeeded or not. Since both firms are symmetric, they receive the same amount of transfer in case of individual success, $m_1 = m_2 = m$. However, the amount of monetary transfers that each firm receives may depend on the type of the project they are working on. Let us denote by \bar{m} and \underline{m} the monetary transfer that each participating firm obtains in case of individual success in a high value and low value project, respectively.

If the Government could unequivocally identify each type of project and distortionary costs were low enough, it would be socially optimal to spend more resources in the high value innovation project than in the low one. However, as with subsidies, if the distortionary cost of public funds were excessive it would be better not to intervene or, in some cases, to reward just high value innovators. Again, if there were no distortion costs for public funds, $\lambda = 0$, first-best equilibrium efforts could be achieved in both types of projects. How this policy changes when the Government suffers an additional adverse selection problem is formally stated in the following proposition.

Proposition 2 *If the Government is unable to distinguish the type of the project, the optimal menu of monetary transfers associated to partial results monitoring $\{\bar{m}; \underline{m}\}$ satisfies the following properties:*

- a) *The optimal monetary transfer coincides for both types of projects, that is $\bar{m} = \underline{m} = \tilde{m}$.*
- b) *There exists an upper bound λ^m such that the optimal transfer is zero above it. Below λ^m , the optimal transfer \tilde{m} is a strictly decreasing and convex function of λ . Moreover, below λ^m the maximum social benefit $W(\tilde{m}, \bar{V}, \underline{V})$ is also a strictly decreasing and convex function of λ .*
- c) *First-best equilibrium effort is never attained for the high value project while the effort implemented for the low value project may be excessive.*

If the Government is unable to distinguish the type of the project and Federal experts are just able to identify partial success, policy makers will be forced to establish the same reward for both types given that low value innovators will act strategically and pretend to be high value. Moreover, as it happens with a subsidy policy, the first-best equilibrium effort is never attained

¹¹Assuming no additional costs to the partial results monitoring process is irrelevant to the main results of the paper.

for the high value projects while research investments may be excessive from a social point of view for the low ones.

3.1.2 Patent subsidies versus partial results monitoring

In this section we will compare optimal solutions obtained through patent subsidies and monitoring, when all Federal experts are able to learn from firms' innovation processes is their potential partial success. If the Government can perfectly distinguish the value of the potential innovation, patent subsidies and partial results monitoring are equivalent policy tools to increase firms' incentives to conduct R&D. They induce the same level of research effort and social expected costs. Although the optimal subsidy for each type is higher than the optimal monetary transfer associated with partial results monitoring, the former is less likely to be paid.

Nevertheless, both policy tools are no longer equivalent if the Government is unable to distinguish the value of the potential innovation. In particular, the unfavorable effects of the adverse selection problem are more intense in monitoring than in the case of subsidies, as it will be formally proved in next proposition.

Proposition 3 *If the Government is unable to distinguish the type of the project, patent subsidies socially dominate partial results monitoring in the sense that they induce higher social benefits.*

Given the additional adverse selection problem the Government is facing, patent subsidies provoke lower social losses than rewards to partial success.¹² The explanation of this result is related with the way each particular policy affects efforts. We know, given their inability to distinguish the type of the project, policy makers are forced to reward both types in the same manner. For both policy tools, high (low) value firms will be rewarded less (more) than the socially optimal and, as a result, high innovators will exert less effort than their first-best while low type's effort may be excessive. Social losses can be measured as the difference between the effort exerted by high value and low value innovators: The higher this difference, the lower the social loss. Monitoring affects efforts more directly than patent subsidies, so making mistakes in setting the right reward for each type of firm has more drastic consequences for the monitoring case. Hence, both type's efforts are closer and social losses higher if a monitoring policy is applied. The result of Proposition 3 is depicted in Figure 2. We plot, for every possible value of the distortion cost λ , the maximum social benefit obtained by subsidies and monitoring, respectively. From Propositions 1 and 2 we know that, for both policy tools, the maximum

¹²This result is even stronger if we assume a cost associated with the partial results monitoring process.

social benefit is a strictly decreasing and convex function of the distortion cost. However, as it is shown in the figure, the maximum social benefit if monitoring is used, $W(\tilde{m}, \bar{V}, \underline{L})$, is smaller than or equal to (in case of no intervention) the maximum social benefit obtained through patent subsidies, $W(\tilde{S}, \bar{V}, \underline{L})$, so patent subsidies are socially dominant.

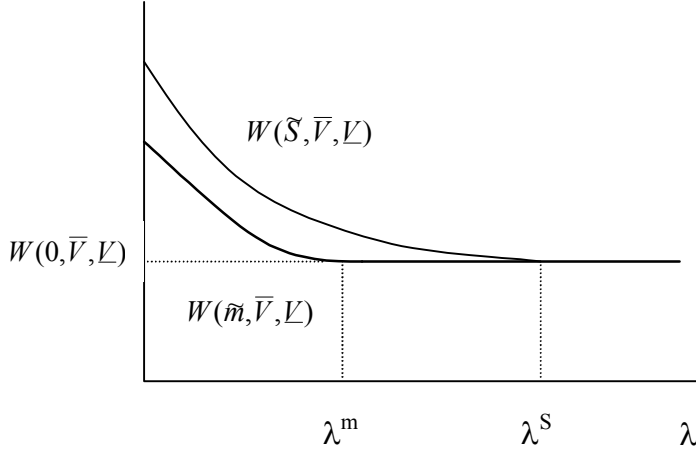


Figure 2: If the Government cannot distinguish the type of the project, patent subsidies dominate partial results monitoring.

Proposition 3 states that if an additional adverse selection arises and the Government can only choose a policy tool to regulate RJV participants and alleviate their free-riding problems, it is socially optimal to use patent subsidies instead of partial results monitoring. However, could policy makers do better if they were able to combine both means of intervention? The answer is no. Through the combination of subsidies and monitoring, the Government has still to prevent firms to lie about their type. Regulator cannot encourage high type firms to innovate without providing the suitable incentives to low value innovators. As a result, research efforts are identical to the case in which only patent subsidies are applied.¹³

Proposition 4 *The Government can do no better when it combines patent subsidies and partial results monitoring than when it simply uses patent subsidies.*

3.1.3 Research efforts monitoring

In this last case, Federal experts are sent to firm's research laboratories and they start a laborious and costly auditing process in order to verify the R&D investment made by RJV participants. We assume after such exhaustive audits, Federal specialists are able to perfectly observe the

¹³Notice that we are assuming the same distortion cost λ for all means of intervention. If these costs were different, it could be optimal to combine both policy tools. This possibility will be considered in the last subsection.

research effort exerted in each laboratory. However, the auditing process is too complex and the Government will only send Federal experts to firms' facilities with some probability $q \in [0, 1]$, identical for both members of the RJV. If Federal experts are sent to research laboratories, the true results of the audits will be published in public documents and noncompliant firms will suffer an adverse publicity and loss of prestige.¹⁴ This shame-based sanction may be particularly efficient in RJV since image and reputation are at the very heart of this business, given the usual need to form research partnerships and obtain external funds.¹⁵ Little sustained success has ever been enjoyed by research laboratories with a bad reputation. Let P denote the expected monetary losses suffered by adverse publicity.¹⁶ The exogenous penalty P is assumed to be identical for both types of projects since negative effects of bad reputation are independent of the value of the current innovation.

Given the shame-based sanction P , the Government must choose the socially optimal audit probability for each type of project, anticipating that RJV participants will behave noncooperatively. Let $q((e, e), V)$ represent the minimum probability of auditing a project of type V to implement (e, e) as a noncooperative Nash equilibrium effort. The following lemma provides some insights about the characteristics of this minimum audit probability.

Lemma 3 *The minimum audit probability for a type V project $q((e, e), V)$ is a strictly increasing function of e and strictly decreasing of P and V .*

Audits imply a fastidious and socially costly process so that Government will set the minimum probability of auditing necessary to implement its research policy. For the sake of simplicity and in order to favour further comparisons with other policy tools, we will assume linear audit costs, $C(q) = kq$, where k is inversely related to the efficiency of Federal experts during the auditing process. Finally, notice that there is a positive relationship between the research effort chosen by the social planner e and its corresponding audit probability $q((e, e), V)$. Hence, it is equivalent for the Government to look for the optimal audit probability or the maximum research effort.

¹⁴There are several criticisms to the use of monetary fines to corporate offenders. Instead of this, French (1984) proposes a shame-based sanction in which noncompliant firms will suffer bad publicity. He called it the "Hester Prynne Sanction", derived from the punishment inflicted in the novel *The Scarlet Letter*.

¹⁵As an example of the relevance of image and reputation, we can refer to the ATP case. The ATP frequently elaborates "an independent, objective and confidential evaluation" of the strength of firms' R&D performance. Many firms have reported that ATP support was an important factor in securing additional funding.

¹⁶This sanction P may reach really high values. In a study of 17 major corporations that have suffered adverse publicity over an offense or serious incident, executives at the middle and higher levels of management reported that loss of corporate prestige was regarded as more serious than the payment of a stiff fine (French, 1984).

If the Government does not face any asymmetric information on the side of the innovation value, it implements higher efforts for the high type project. It is obvious that the monitoring policy has no effect on firms' incentives to innovate if the auditing process is not connected to any real sanction. Shame-based sanctions are designed to threaten prestige and image but they can only be effective if the noncompliant firm does regard social stigmatization as a matter of importance. If this is not the case, the monitoring policy is completely useless and the probability of auditing becomes a vain threat. However, whenever researchers care for a good reputation and prestige the monitoring policy will yield to higher R&D investments than without intervention. In particular, if the auditing process is totally costless, first-best equilibrium efforts are implemented for each type of project. Next proposition shows that all these results continue to hold even if the Government becomes unable to distinguish whether an innovation is high or not.

Proposition 5 *The optimal menu of research efforts and audit probabilities $\{[(\bar{e}, \bar{e}), q((\bar{e}, \bar{e}), \bar{V})]; [(\underline{e}, \underline{e}), q((\underline{e}, \underline{e}), \underline{V})]\}$ coincides for the case in which the Government can and cannot distinguish the type of the project .*

Proposition 5 states that the adverse selection problem does not have any effect on the optimal monitoring policy if real research efforts can be perfectly observed through an auditing process. Firms' incentives to behave opportunistically and untruthfully reveal their type disappear if Federal auditors can verify efforts and force them to exert the effort of the revealed type. The main difference with other policy tools is that efforts are verifiable and hence firms are obliged to exert the research effort they announced. On the contrary, with patent subsidies and partial results monitoring, firms receive the monetary transfers corresponding to the type they announce but they exert the effort corresponding to their true type. Low value innovators are willing to receive as much money as high value innovators but they do not want to exert as much research effort as high value firms do. As a result, if efforts are perfectly observable the incentives for low value researchers to lie about their type entirely disappear.

3.1.4 Patent subsidies versus research effort monitoring

Now we will compare patent subsidies and monitoring when Federal experts are able to verify firms' research efforts through an auditing process. Recall it is not in the interest of low value innovators to truthfully reveal their type in a patent subsidy policy and the adverse selection problem negatively affects optimal results. On the other hand, if firms are monitored the adverse selection problem vanishes as it was proved in Proposition 5 and monitoring may socially dominate patent subsidies. This is formally stated in the following proposition.

Proposition 6 *If patent subsidies and research effort monitoring are equivalent policy tools to alleviate firms' free-riding problem when the Government can distinguish the type of the project, in the sense that they yield the same level of research effort or social benefit, patent subsidies are socially dominated by effort monitoring when the Government cannot distinguish the type of the project.*

Once again we should wonder whether the Government can improve social benefit combining both monitoring and patent subsidies. The answer is still negative if the shamed-based sanction is sufficiently high. The reason is that though patent subsidies and monitoring may be equally effective to solve the moral hazard problem, the former implies a higher social cost than research effort monitoring. Then, it is not sensible for the social planner to combine both policy tools.

Proposition 7 *If P is sufficiently high and λ small enough and patent subsidies and research effort monitoring implement the same level of research effort when the Government can distinguish the type of the project, the Government can do no better when it combines patent subsidies and effort monitoring than when it simply uses effort monitoring.*

3.1.5 Optimal combination if subsidies and monitoring are not ex-ante equivalent

Finally, we should briefly comment when it is optimal to combine patent subsidies and monitoring tools. Along the paper, we have considered equivalent policy tools in the absence of any adverse selection problem and we have argued that it is not sensible for regulators to combine patent subsidies and monitoring. Obviously this is not longer true if policy tools are not ex-ante equivalent, that is, if they are associated with different social costs before the adverse selection problem arises. There are two ways in which policies can differ in these social costs. On the one hand, we have assumed that public funds are obtained through distortionary taxation and distortion costs are identical for all means of intervention. However, policies may differ in the distortion cost. The distortion cost of public funds depends on the specific characteristics of the fiscal program, such as the kind of tax instruments used. We know patent subsidies require the Government to spend more public resources than partial results monitoring (though they are less likely to be paid). Thus, patent subsidies may involve more tax instruments than partial results monitoring and induce higher distortion costs.¹⁷ On the other hand, policies may differ in how expensive are the processes they imply. In this sense, the auditing process necessary to

¹⁷Hansson and Stuart (1985), in a study of the Swedish fiscal program, conclude that taxes on capital are more distortionary than taxes on labor. Hence if, for example, partial results monitoring is financed just through taxes on labor but patent subsidies require both taxes on capital and taxes on labor, the latter would induce higher distortion costs than the former.

verify real research efforts may result extremely costly to be performed in both types of projects and the Government may be interested in combining this policy with patent subsidies.

It is optimal to combine patent subsidies and monitoring if the most effective policy tool turns out to be also the most expensive. The optimal combination of subsidies and monitoring goes through applying more intensively the most effective policy tool to high value innovators, that is, patent subsidies if only partial results can be observable or monitoring if research efforts become verifiable. However, the Government should provide low value innovators the right incentives to tell the truth while encouraging high value innovators to increase their research efforts.

Corollary 1 *If the Government is unable to distinguish the type of the project, it may be optimal to combine patent subsidies and monitoring. In particular, if partial results monitoring implies lower social costs than patent subsidies, it is optimal to monitor more the low value innovators $\bar{m} \leq \underline{m}$ and give higher subsidies to high value firms $\bar{S} \geq \underline{S}$. On the other hand, if patent subsidies are less costly than research effort monitoring, it is socially optimal to monitor more the high value innovators $\bar{e} \geq \underline{e}$ and give higher subsidies to low value firms $\bar{S} \leq \underline{S}$.*

From Corollary 1 we can conclude that a combination of subsidies and monitoring may be socially optimal if both means of intervention imply different social costs. In all cases, the Government should apply more intensively to high value innovators the most effective, though most expensive, policy tool. To be precise, if partial results monitoring is comparatively cheaper than patent subsidies it is optimal to monitor more the low value innovators and give higher subsidies to high value firms. Obviously, if partial results monitoring is more expensive than patent subsidies, combination has no sense since the former is also more inefficient. On the other hand, if patent subsidies are less costly than research effort monitoring, it is socially optimal to monitor more the high value firms and give higher subsidies to low value projects.¹⁸ Again, no combination is sensible if research efforts monitoring is cheaper than patent subsidies, since it is also more efficient.

4 Conclusions

It is usually the case that when a third party tries to solve a problem between two agents, it is unable to find out all the relevant information. Although some tools may be equivalent to solve the initial problem of agents, they are no longer equivalent if some information is missing.

¹⁸Similar conclusion can be found in Caballero (1999).

We provide a clear application of this fact related with firms' incentives to invest in R&D in collaborative projects.

In R&D collaborative projects where firms' actions are not verifiable, the problems of opportunism and asymmetric information reduce the incentives to exert research effort and lead to an insufficient investment in R&D. The Government trying to solve the underprovision of efforts faces an additional adverse selection problem, given its inability to distinguish precisely how much money innovators will be able to make from patents.

We focus on two different means of public intervention, patent subsidies and monitoring, because of their extensive use as policy tools. We assume two possible monitoring systems, one where the Government is able to observe just partial results and one where the Government is able to observe the real research effort exerted by firms. The first monitoring system may correspond to high technology industries in which observing research efforts may result specially hard.

We consider as benchmark a situation in which patent subsidies and both monitoring systems are equivalent policies to increase firms' incentives to conduct R&D. Although subsidies and monitoring are ex-ante equivalent, they imply different social losses if an additional adverse selection problem arises. In particular, if the Government cannot observe research efforts, patent subsidies must be applied while monitoring is the optimal policy if efforts become verifiable. Therefore, the supremacy of monitoring tools over patent subsidies is clearly dependent on which type of information the Government can obtain about firms' R&D performance. Moreover, if subsidies and monitoring are not ex-ante equivalent and differ in their costs, it might be optimal to combine them. Combination is only sensible if the most effective policy tool is also the most expensive. In each case, it is optimal to apply more intensively the most effective, though most expensive, policy tool to high value innovators. To be more precise, if partial results monitoring is cheaper than patent subsidies, it is optimal to give higher subsidies to high value innovators and monitor more the low value ones. However, if patent subsidies are less costly than research effort monitoring, it is better to monitor more the high value projects and give higher subsidies to low value ones.

Finally, it is worth highlighting that the main conclusions can be extended to other economic areas, such as environmental economics. As an example, consider two pollutant firms along a river whose property rights belong to fishermen. Each pollutant firm makes independent emissions that may damage the quality of the water and whose combination may produce an environmental disaster. If independent emissions pollute the river each firm i has to pay w_i to fishermen and if an environmental disaster occurs they have to jointly compensate fishermen

with an amount $V \in \{\bar{V}, \underline{V}\}$ strictly higher than w_i for every firm i . The degree of the potential disaster is common knowledge for both firms but neither the fishermen nor the regulator are able to precisely anticipate the nature of such a disaster. All they know is the probability $p \in [0, 1]$ of a great environmental calamity, $\bar{V} > \underline{V}$. Finally, assume firms may be able to reduce their emissions and decrease the probability of polluting the river. This abatement effort is not verifiable and privately costly so firms suffer a double-sided moral hazard problem. The Government may be interested in raising firms' incentives to abate but it would face an additional adverse selection problem, given its inability to anticipate the degree of the potential environmental disaster. In this case the relevant policy tools are monitoring and sanctions in case of disaster and the optimal policy choice will again depend on how informative is the monitoring process.

Appendix

Proof of Lemma 2. It is not difficult to see that the sum of noncooperative research efforts $e_1^{nc}(V) + e_2^{nc}(V)$ is maximal for an egalitarian sharing rule. For $\alpha_i = 1/2$, it can be easily obtained that $e^*(V) = w/(\theta - V)$ which is strictly larger than $e^{nc}(V) = w/(\theta - V/2)$. ■

Proof of Proposition 1. The Government solves the following maximization program:

$$\underset{\bar{S}, \underline{S}}{Max} \{2p[\Pi(e(\bar{S}, \bar{V}), \bar{S}, \bar{V}) - (1 + \lambda)e^2(\bar{S}, \bar{V})\bar{S}] + 2(1 - p)[\Pi(e(\underline{S}, \underline{V}), \underline{S}, \underline{V}) - (1 + \lambda)e^2(\underline{S}, \underline{V})\underline{S}]\}$$

subject to

- (1) $\Pi(e(\bar{S}, \bar{V}), \bar{S}, \bar{V}) \geq \Pi(e(\underline{S}, \bar{V}), \underline{S}, \bar{V})$
- (2) $\Pi(e(\underline{S}, \underline{V}), \underline{S}, \underline{V}) \geq \Pi(e(\bar{S}, \underline{V}), \bar{S}, \underline{V})$
- (3) $\Pi(e(\bar{S}, \bar{V}), \bar{S}, \bar{V}) \geq \Pi(e(0, \bar{V}), 0, \bar{V})$
- (4) $\Pi(e(\underline{S}, \underline{V}), \underline{S}, \underline{V}) \geq \Pi(e(0, \underline{V}), 0, \underline{V})$
- (5) $\bar{S} \geq 0$
- (6) $\underline{S} \geq 0$,

where $e(S, V)$ is the noncooperative Nash equilibrium effort given the patent subsidy S , that is, $e(S, V) = \frac{w}{\theta - \frac{V}{2} - S}$.

Expressions (1) and (2) represent the incentive compatibility constraints for each type of project and they imply that no type wants to lie. For both constraints to be satisfied it is easy to show that if there exists a solution it must satisfy that $\bar{S} = \underline{S} = \tilde{S}$. Expressions (3) and (4) represent the participation constraints for each type of project and they imply that no one is worse off than without intervention. They are satisfied if expressions (5) and (6) are satisfied. Then, the regulator's program can be rewritten as:

$$\underset{S}{Max} \{W(S, \bar{V}, \underline{V}) = 2pf(S, \bar{V}) + 2(1 - p)f(S, \underline{V})\}$$

subject to $S \geq 0$,

where $f(S, V) = \frac{w^2}{(\theta - \frac{V}{2} - S)^2} [\frac{\theta}{2} - (1 + \lambda)S]$ with $V \in \{\bar{V}, \underline{V}\}$.

The following steps can simply be obtained by computing the derivatives of $W(S, \bar{V}, \underline{V})$ with respect to S and λ .

Step 1.1 If $\theta > 2\bar{V}$, the social objective function $W(S, \bar{V}, \underline{V})$ is strictly concave in S for every $S \geq 0$ and strictly decreasing in S for every $S \geq \bar{V}/2$.

Step 1.2 If $\theta > 2\bar{V}$, the social objective function $W(S, \bar{V}, \underline{V})$ and its first derivative with respect to S are strictly decreasing in λ for every $S > 0$.

Step 1.3 If $\theta > 2\bar{V}$, the second derivative of $W(S, \bar{V}, \underline{V})$ with respect to S is strictly decreasing in λ and its first derivative with respect to S is linear in λ .

Step 1.4 $\frac{\partial W}{\partial S}(0, \bar{V}, \underline{V}) = 0$ if and only if $\lambda = \lambda^S > 0$.

From steps 1.2 and 1.4 we can conclude that the optimal subsidy is zero above λ^S and strictly positive below it. For every $\lambda \in [0, \lambda^S)$, $\frac{\partial W}{\partial S}(\tilde{S}, \bar{V}, \underline{V}) = 0$ defines \tilde{S} implicitly as a function of λ . Applying the implicit function theorem, the envelope theorem and previous steps, it is not difficult to prove that the optimal subsidy and the maximum social benefit are strictly decreasing and convex functions of λ . Finally, we should prove that the optimal subsidy is never above $\bar{V}/2$ but there always exists a lower bound λ_S such that below it $\tilde{S} > \underline{V}/2$. From step 1.1 we can deduce that the optimal subsidy is never above $\bar{V}/2$. To prove that there exists a lower bound λ_S such that below it $\tilde{S} > \underline{V}/2$, it is sufficient to verify that $\frac{\partial W}{\partial S}(\frac{V}{2}, \bar{V}, \underline{V}) > 0$ for $\lambda = 0$. ■

Proof of Proposition 2. The Government solves the following maximization program:

$$\underset{\bar{m}, \underline{m}}{\text{Max}} \{2p[\Pi(e(\bar{m}, \bar{V}), \bar{m}, \bar{V}) - (1 + \lambda)e(\bar{m}, \bar{V})\bar{m}] + 2(1 - p)[\Pi(e(\underline{m}, \underline{V}), \underline{m}, \underline{V}) - (1 + \lambda)e(\underline{m}, \underline{V})\underline{m}]\}$$

subject to

- (1) $\Pi(e(\bar{m}, \bar{V}), \bar{m}, \bar{V}) \geq \Pi(e(\underline{m}, \bar{V}), \underline{m}, \bar{V})$
- (2) $\Pi(e(\underline{m}, \underline{V}), \underline{m}, \underline{V}) \geq \Pi(e(\bar{m}, \underline{V}), \bar{m}, \underline{V})$
- (3) $\Pi(e(\bar{m}, \bar{V}), \bar{m}, \bar{V}) \geq \Pi(e(0, \bar{V}), 0, \bar{V})$
- (4) $\Pi(e(\underline{m}, \underline{V}), \underline{m}, \underline{V}) \geq \Pi(e(0, \underline{V}), 0, \underline{V})$
- (5) $\bar{m} \geq 0$
- (6) $\underline{m} \geq 0$,

where $e(m, V)$ is the noncooperative Nash equilibrium effort given the monetary transfer m , that is, $e(S, V) = \frac{w+m}{\theta - \frac{V}{2}}$.

Both compatibility constraints (1) and (2) are fulfilled if $\bar{m} = \underline{m} = \tilde{m}$ holds. Participation constraints (3) and (4) are satisfied if so are expressions (5) and (6). Then, the social planner solves:

$$\begin{aligned} & \underset{m}{\text{Max}} \{W(m, \bar{V}, \underline{V}) = 2pf(m, \bar{V}) + 2(1-p)f(m, \underline{V})\} \\ & \text{subject to } m \geq 0 \\ & \text{where } f(m, V) = \frac{w+m}{\theta-\frac{V}{2}} \left[\frac{w+m}{\theta-\frac{V}{2}} \frac{\theta}{2} - (1+\lambda)m \right] \text{ with } V \in \{\bar{V}, \underline{V}\}. \end{aligned}$$

Step 2.1 If $\theta > 2\bar{V}$, the social objective function $W(m, \bar{V}, \underline{V})$ is strictly concave in m for every $m \geq 0$ and strictly decreasing in m for every $m \geq \bar{V}w/(2\theta - 2\bar{V})$.

Step 2.2 If $\theta > 2\bar{V}$, the social objective function $W(m, \bar{V}, \underline{V})$ and its first derivative with respect to m are strictly decreasing in λ for every $m > 0$.

Step 2.3 If $\theta > 2\bar{V}$, the second derivative of $W(m, \bar{V}, \underline{V})$ with respect to m is strictly decreasing in λ and its first derivative with respect to m is linear in λ .

Step 2.4 $\frac{\partial W}{\partial m}(0, \bar{V}, \underline{V}) = 0$ if and only if $\lambda = \lambda^m > 0$.

From previous steps, we can conclude that the optimal monetary transfer is zero above λ^m and strictly positive below it. For every $\lambda \in [0, \lambda^m)$, $\frac{\partial W}{\partial m}(\tilde{m}, \bar{V}, \underline{V}) = 0$ defines \tilde{m} implicitly as a function of λ . Applying the implicit function theorem, the envelope theorem and previous steps, it is not difficult to prove that the optimal transfer and the maximum social benefit are strictly decreasing and convex functions of λ . Finally, we should prove that the optimal transfer is never above $\bar{V}w/(2\theta - 2\bar{V})$ but there always exists a lower bound λ_m such that below it $\tilde{m} > \underline{V}w/(2\theta - 2\underline{V})$. From step 2.1, it is obvious that the optimal transfer is never above $\bar{V}w/(2\theta - 2\bar{V})$. To prove that there exist a lower bound λ_m such that below it $\tilde{m} > \underline{V}w/(2\theta - 2\underline{V})$, it is sufficient to verify that $\frac{\partial W}{\partial m}(\frac{\underline{V}w}{2\theta - 2\underline{V}}, \bar{V}, \underline{V}) > 0$ for $\lambda = 0$. This completes the proof. ■

Proof of Proposition 3. We know from Propositions 1 and 2 that the optimal patent subsidy \tilde{S} and the optimal monetary transfer \tilde{m} are zero for distortionary costs above λ^S and λ^m , respectively. Below λ^S and λ^m , the corresponding maximum social benefits $W(\tilde{S}, \bar{V}, \underline{V})$ and $W(\tilde{m}, \bar{V}, \underline{V})$ are strictly decreasing and convex functions in λ .

First, it can be checked that $\lambda^S > \lambda^m$ for every $p \in (0, 1)$ and $\bar{V} > \underline{V}$, that is whenever there is an additional adverse selection problem. Second, since both maximum social benefits are strictly decreasing and convex functions in λ , it is sufficient to check that for no distortionary costs patent subsidies induce higher social benefits. In particular, it can be proven that for $\lambda = 0$ it holds that: $W(\tilde{S}, \bar{V}, \underline{V}) \geq W(p\frac{\bar{V}}{2} + (1-p)\frac{\underline{V}}{2}, \bar{V}, \underline{V}) > W(\tilde{m}, \bar{V}, \underline{V})$ for every $p \in (0, 1)$ and $\bar{V} > \underline{V}$. This completes the proof. ■

Proof of Proposition 4. If the Government is interested in combining both partial results monitoring and patent subsidies, it will have to solve the following maximization program:

$$\begin{array}{l} \text{Max} \\ (\bar{S}, \bar{m}), (\underline{S}, \underline{m}) \end{array} \left\{ \begin{array}{l} 2p [\Pi(e(\bar{m}, \bar{S}, \bar{V}), \bar{m}, \bar{S}, \bar{V}) - (1 + \lambda)e^2(\bar{m}, \bar{S}, \bar{V})\bar{S} - (1 + \lambda)e(\bar{m}, \bar{S}, \bar{V})\bar{m}] \\ + 2(1 - p) [\Pi(e(\underline{m}, \underline{S}, \underline{V}), \underline{m}, \underline{S}, \underline{V}) - (1 + \lambda)e^2(\underline{m}, \underline{S}, \underline{V})\underline{S} - (1 + \lambda)e(\underline{m}, \underline{S}, \underline{V})\underline{m}] \end{array} \right\}$$

subject to

- (1) $\Pi(e(\bar{m}, \bar{S}, \bar{V}), \bar{m}, \bar{S}, \bar{V}) \geq \Pi(e(\underline{m}, \underline{S}, \bar{V}), \underline{m}, \underline{S}, \bar{V})$
- (2) $\Pi(e(\underline{m}, \underline{S}, \underline{V}), \underline{m}, \underline{S}, \underline{V}) \geq \Pi(e(\bar{m}, \bar{S}, \underline{V}), \bar{m}, \bar{S}, \underline{V})$
- (3) $\Pi(e(\bar{m}, \bar{S}, \bar{V}), \bar{m}, \bar{S}, \bar{V}) \geq \Pi(e(0, 0, \bar{V}), 0, 0, \bar{V})$
- (4) $\Pi(e(\underline{m}, \underline{S}, \underline{V}), \underline{m}, \underline{S}, \underline{V}) \geq \Pi(e(0, 0, \underline{V}), 0, 0, \underline{V})$
- (5) $\bar{m} \geq 0$
- (6) $\underline{m} \geq 0$
- (7) $\bar{S} \geq 0$
- (8) $\underline{S} \geq 0$,

where $e(m, S, V)$ is the noncooperative Nash equilibrium effort given the monetary transfer m and patent subsidy S , that is, $e(m, S, V) = \frac{w+m}{\theta - \frac{V}{2} - S}$.

Constraints (1) and (2) represent the incentive compatibility constraints. Since profits are strictly increasing in research efforts, expressions (1) and (2) just imply that firms' efforts are higher under their own contract than under the other type's, that is $e(\bar{m}, \bar{S}, \bar{V}) > e(\underline{m}, \underline{S}, \bar{V})$ and $e(\underline{m}, \underline{S}, \underline{V}) < e(\bar{m}, \bar{S}, \underline{V})$, respectively. These conditions can be rewritten as:

$$\begin{aligned} (1') \quad (\bar{m} - \underline{m})(\theta - \frac{\bar{V}}{2}) &\geq w(\underline{S} - \bar{S}) - \underline{m}\bar{S} + \bar{m}\underline{S} \\ (2') \quad (\bar{m} - \underline{m})(\theta - \frac{\underline{V}}{2}) &\geq w(\underline{S} - \bar{S}) - \underline{m}\bar{S} + \bar{m}\underline{S}. \end{aligned}$$

For both expressions (1') and (2') to be satisfied it is easy to see that $\underline{m} \geq \bar{m}$ is a necessary condition. Again, if $\underline{m} \geq \bar{m}$ is satisfied, $\bar{S} \geq \underline{S}$ is a necessary condition for condition (1') to hold. The main characteristics of the optimal separating menu of subsidies and monetary transfers of this program are summarized in the following step (the proof is provided below).

Step 4.1 The optimal separating menu of monetary transfers associated with partial results monitoring and patent subsidies $\{(\bar{m}, \bar{S}); (\underline{m}, \underline{S})\}$ satisfies the following properties:

- a) The incentive compatibility constraint for low value innovators binds though the incentive compatibility constraint for high value firms is not binding.
- b) The optimal monetary transfers and subsidies satisfy that $\underline{m} > \bar{m} = 0$ and $\bar{S} > \underline{S}$.

Now we have to prove that any separating equilibrium $\{(0, \bar{S}); (\underline{m}, \underline{S})\}$ yields identical research efforts for each type of project to the pooling equilibrium $\{\tilde{S}; \tilde{S}\}$, that is $e(0, \bar{S}, \bar{V}) = e(0, \tilde{S}, \bar{V})$ and $e(\underline{m}, \underline{S}, \underline{V}) = e(0, \tilde{S}, \underline{V})$.

We will prove it by contradiction. Assume research efforts are not identical. Then, we must have any of the four following cases, each one with at least one strict inequality.

1. $e(0, \bar{S}, \bar{V}) \geq e(0, \tilde{S}, \bar{V})$ and $e(\underline{m}, \underline{S}, \underline{V}) \leq e(0, \tilde{S}, \underline{V})$.
2. $e(0, \bar{S}, \bar{V}) \leq e(0, \tilde{S}, \bar{V})$ and $e(\underline{m}, \underline{S}, \underline{V}) \geq e(0, \tilde{S}, \underline{V})$.
3. $e(0, \bar{S}, \bar{V}) \leq e(0, \tilde{S}, \bar{V})$ and $e(\underline{m}, \underline{S}, \underline{V}) \leq e(0, \tilde{S}, \underline{V})$.
4. $e(0, \bar{S}, \bar{V}) \geq e(0, \tilde{S}, \bar{V})$ and $e(\underline{m}, \underline{S}, \underline{V}) \geq e(0, \tilde{S}, \underline{V})$.

Let us analyze each case separately.

Case 1. First of all, notice that $e(0, \bar{S}, \bar{V}) \geq e(0, \tilde{S}, \bar{V})$ is satisfied if and only if $\bar{S} \geq \tilde{S}$. Secondly, $e(\underline{m}, \underline{S}, \underline{V}) \leq e(0, \tilde{S}, \underline{V})$ holds if and only if:

$$\frac{w + \underline{m}}{\theta - \frac{V}{2} - \underline{S}} \leq \frac{w}{\theta - \frac{V}{2} - \tilde{S}}.$$

We know the incentive compatibility constraint for a low value firm binds so it must be satisfied that:

$$\frac{w + \underline{m}}{\theta - \frac{V}{2} - \underline{S}} = \frac{w}{\theta - \frac{V}{2} - \tilde{S}}.$$

But since $\bar{S} \geq \tilde{S}$ we run into a contradiction if there is any strict inequality.

Case 2. Again, on the one hand, notice that $e(0, \bar{S}, \bar{V}) \leq e(0, \tilde{S}, \bar{V})$ holds if and only if $\bar{S} \leq \tilde{S}$. On the other hand, $e(\underline{m}, \underline{S}, \underline{V}) \geq e(0, \tilde{S}, \underline{V})$ is satisfied if and only if:

$$\frac{w + \underline{m}}{\theta - \frac{V}{2} - \underline{S}} \geq \frac{w}{\theta - \frac{V}{2} - \tilde{S}}.$$

But since the incentive compatibility constraint for a low value firm binds and $\bar{S} \leq \tilde{S}$ we get into a contradiction if there is any strict inequality.

Case 3. This case is trivial. We have that it must hold that $\bar{S} \leq \tilde{S}$ and $\underline{S} \leq \tilde{S}$. Given that an increase in \underline{m} , \underline{S} or \bar{S} has the same associated distortion cost that an increase in \tilde{S} and \tilde{S} is a social optimum, we can conclude that \underline{m} , \underline{S} and \bar{S} cannot be optimal (if there is any strict inequality).

Case 4. This is similar to the previous case.

This completes the proof. ■

Proof of Step 4.1. Recall the maximization program of the Government is given by:

$$\begin{aligned} \underset{(\bar{S}, \bar{m}), (\underline{S}, \underline{m})}{Max} \quad & 2p [\Pi(e(\bar{m}, \bar{S}, \bar{V}), \bar{m}, \bar{S}, \bar{V}) - (1 + \lambda)e^2(\bar{m}, \bar{S}, \bar{V})\bar{S} - (1 + \lambda)e(\bar{m}, \bar{S}, \bar{V})\bar{m}] \\ & + 2(1 - p) [\Pi(e(\underline{m}, \underline{S}, \underline{V}), \underline{m}, \underline{S}, \underline{V}) - (1 + \lambda)e^2(\underline{m}, \underline{S}, \underline{V})\underline{S} - (1 + \lambda)e(\underline{m}, \underline{S}, \underline{V})\underline{m}] \end{aligned}$$

subject to

- (1) $\Pi(e(\bar{m}, \bar{S}, \bar{V}), \bar{m}, \bar{S}, \bar{V}) \geq \Pi(e(\underline{m}, \underline{S}, \bar{V}), \underline{m}, \underline{S}, \bar{V})$
- (2) $\Pi(e(\underline{m}, \underline{S}, \underline{V}), \underline{m}, \underline{S}, \underline{V}) \geq \Pi(e(\bar{m}, \bar{S}, \underline{V}), \bar{m}, \bar{S}, \underline{V})$
- (3) $\Pi(e(\bar{m}, \bar{S}, \bar{V}), \bar{m}, \bar{S}, \bar{V}) \geq \Pi(e(0, 0, \bar{V}), 0, 0, \bar{V})$
- (4) $\Pi(e(\underline{m}, \underline{S}, \underline{V}), \underline{m}, \underline{S}, \underline{V}) \geq \Pi(e(0, 0, \underline{V}), 0, 0, \underline{V})$
- (5) $\bar{m} \geq 0$
- (6) $\underline{m} \geq 0$
- (7) $\bar{S} \geq 0$
- (8) $\underline{S} \geq 0$.

First of all, notice that the participation constraints (3) and (4) are implied by the non-negative constraints (5), (6), (7) and (8). Through some manipulations, regulator's program can be rewritten as:

$$\underset{(\bar{S}, \bar{m}), (\underline{S}, \underline{m})}{Max} \quad pf(\bar{m}, \bar{S}, \bar{V}) + (1 - p)f(\underline{m}, \underline{S}, \underline{V})$$

subject to

- (λ_1) $\bar{S} - \frac{(\underline{m} - \bar{m})(\theta - \frac{V}{2}) + (\bar{m} + w)\underline{S}}{m + w} \geq 0$
- (λ_2) $\frac{(\underline{m} - \bar{m})(\theta - \frac{V}{2}) + (\bar{m} + w)\underline{S}}{m + w} - \bar{S} \geq 0$
- (λ_3) $\bar{m} \geq 0$
- (λ_4) $\underline{m} \geq 0$
- (λ_5) $\bar{S} \geq 0$
- (λ_6) $\underline{S} \geq 0$,

where $f(m, S, V) = e(m, S, V) [(\theta - 2(1 + \lambda)S)e(m, S, V) - 2(1 + \lambda)m]$ and λ_i is the Lagrange multiplier corresponding to constraint i .

The first order conditions of the Lagrange function with respect to \bar{S} , \underline{S} , \bar{m} , and \underline{m} yield the

following:

$$p \frac{\partial f(\bar{m}, \bar{S}, \bar{V})}{\partial \bar{S}} + \lambda_1 - \lambda_2 + \lambda_5 = 0 \quad (A)$$

$$(1-p) \frac{\partial f(\underline{m}, \underline{S}, \underline{V})}{\partial \underline{S}} + (\lambda_2 - \lambda_1) \frac{\bar{m} + w}{\underline{m} + w} + \lambda_6 = 0 \quad (B)$$

$$p \frac{\partial f(\bar{m}, \bar{S}, \bar{V})}{\partial \bar{m}} + \lambda_1 \frac{\theta - \frac{\bar{V}}{2} - \underline{S}}{\underline{m} + w} - \lambda_2 \frac{\theta - \frac{\underline{V}}{2} - \underline{S}}{\underline{m} + w} + \lambda_3 = 0 \quad (C)$$

$$(1-p) \frac{\partial f(\underline{m}, \underline{S}, \underline{V})}{\partial \underline{m}} - \lambda_1 \frac{(\bar{m} + w)(\theta - \frac{\bar{V}}{2} - \underline{S})}{(\underline{m} + w)^2} + \lambda_2 \frac{(\bar{m} + w)(\theta - \frac{\underline{V}}{2} - \underline{S})}{(\underline{m} + w)^2} + \lambda_4 = 0 \quad (D)$$

A separating menu of patent subsidies and monetary transfers exists if $\underline{m} > \bar{m} \geq 0$ and $\bar{S} > \underline{S} \geq 0$, that is $\lambda_4 = \lambda_5 = 0$, and if any of the following possibilities holds:

1. $\lambda_1 = \lambda_2 = 0$.
2. $\lambda_1 > 0, \lambda_2 = 0$.
3. $\lambda_1 = 0, \lambda_2 > 0$.¹⁹

In order to prove that only the incentive compatibility constraint for low value innovators binds we have to verify that only the third case holds. We will do the proof by contradiction.

Case 1. Assume $\lambda_1 = \lambda_2 = 0$. In this case, expressions (A) and (D) are just the first order conditions of the social objective function with respect to \underline{m} and \bar{S} . Let us denote \underline{m}^* and \bar{S}^* the solutions of those first order conditions. Since $\lambda_2 = 0$, the incentive compatibility constraint for low value innovators is not binding. However, one can show that

$$\frac{(\underline{m}^* - \bar{m})(\theta - \frac{\underline{V}}{2}) + (\bar{m} + w)\underline{S}}{\underline{m}^* + w} - \bar{S}^* \geq 0,$$

is never satisfied for every non-negative \bar{m} and \underline{S} (and in particular, it is not satisfied for the optimal solutions \bar{m}^* and \underline{S}^*). This yields a contradiction and we can conclude that it is not possible that $\lambda_1 = \lambda_2 = 0$.

Case 2. Assume $\lambda_1 > 0, \lambda_2 = 0$. Since $\lambda_1 = 0$, the incentive compatibility constraint for high value innovators binds, that is, in the optimum it must be satisfied that:

$$\bar{S}^* = \frac{(\underline{m}^* - \bar{m}^*)(\theta - \frac{\bar{V}}{2}) + (\bar{m}^* + w)\underline{S}^*}{\underline{m}^* + w}$$

From condition (A) we can rewrite λ_1 as a function of $\bar{m}^*, \underline{m}^*$ and \bar{S}^* :

$$\lambda_1 = -p \frac{\partial f(\bar{m}, \bar{S}^*, \bar{V})}{\partial \bar{S}}.$$

¹⁹Notice that the case in which both Lagrange multipliers are positive corresponds to the pooling equilibrium.

Given the value of λ_1 , it can be verified that:

$$p \frac{\partial f(\bar{m}, \bar{S}^*, \bar{V})}{\partial \bar{m}} + \lambda_1 \frac{\theta - \frac{\bar{V}}{2} - \underline{S}}{\underline{m} + w} = 0.$$

Then, for condition (C) to hold it must be satisfied that $\lambda_3 = 0$, that is \bar{m}^* is strictly positive. Substituting the value of λ_1 in condition (D), and given that $\lambda_2 = \lambda_4 = 0$, we can easily obtain the optimal value of \underline{m} , as a function of \underline{S} , $\underline{m}^* = \underline{m}(\underline{S})$. Now we have to obtain the optimal value of \bar{S} . Suppose \underline{S} is positive, that is $\lambda_6 = 0$. Then from condition (B) we can obtain the optimal value of \underline{S} as a function of \underline{m} , $\underline{S}^* = \underline{S}(\underline{m})$. Solving the system of equations given by $\underline{m}^* = \underline{m}(\underline{S})$ and $\underline{S}^* = \underline{S}(\underline{m})$ we obtain a negative value for \underline{m}^* which contradicts the assumption of \underline{m} being nonnegative. Thus, we can conclude that it must be true that $\underline{S}^* = 0$ and λ_6 is positive. Finally, substituting $\underline{m}^* = \underline{m}(\underline{S}^* = 0)$, $\underline{S}^* = 0$ and $\bar{m}^* > 0$ in the value of λ_1 we obtain a negative value, which contradicts the assumption of λ_1 being positive. Hence, we can conclude that $\lambda_1 > 0$ and $\lambda_2 = 0$ is not possible.

Case 3. We have already proved by contradiction that if there exists a separating menu of patent subsidies and monetary transfers it must satisfy that $\lambda_1 = 0$ and $\lambda_2 > 0$. In this case, the incentive compatibility constraint for the low value innovators binds and the following is satisfied:

$$\bar{S}^* = \frac{(\underline{m} - \bar{m})(\theta - \frac{V}{2}) + (\bar{m} + w)\underline{S}}{\underline{m} + w}$$

$$\lambda_2 = p \frac{\partial f(\bar{m}, \bar{S}^*, \bar{V})}{\partial \bar{S}}.$$

We proceed to prove that $\bar{m}^* = 0$. Let us do it by contradiction. Assume \bar{m}^* is positive and $\lambda_3 = 0$. Then, from condition (C) we can easily obtain the optimal value of \bar{m} as a function of \underline{S} and \underline{m} and from condition (D), the optimal value of \underline{m} as a function of \underline{S} and \bar{m} . Solving this system of equations, we obtain a negative solution for \bar{m}^* . This contradicts the fact of \bar{m}^* being positive and we can deduce that $\bar{m}^* = 0$ and λ_3 is positive. There exists a multiple optimal solution for \underline{m} and \underline{S} . In particular, given the value of λ_2 , if \underline{S}^* is strictly positive the optimal solution satisfies:

$$(1 - p) \frac{\partial f(\underline{m}^*, \underline{S}^*, \underline{V})}{\partial \underline{S}} + \lambda_2 \frac{w}{\underline{m}^* + w} = 0$$

$$(1 - p) \frac{\partial f(\underline{m}^*, \underline{S}^*, \underline{V})}{\partial \underline{m}} + \lambda_2 \frac{w(\theta - \frac{V}{2} - \underline{S}^*)}{(\underline{m}^* + w)^2} = 0.$$

If \underline{S}^* is zero, the optimal solution is given by the second equation of the above system.

This completes the proof. ■

Proof of Lemma 3. In order to implement the efforts (e, e) as a noncooperative Nash equilibrium, it must be satisfied that no single firm has incentives to deviate and exert a different effort, that is it must be hold that

$$\Pi_i(e, e) \geq \Pi_i(e_i(e, V), e) - qP, \quad (2)$$

where $e_i(e, V) = \frac{Ve+2w}{2\theta}$ represents firm i 's reaction function, given that firm j is exerting an effort e . Condition (2) can be rewritten as

$$e^2\left(\frac{V}{2} - \frac{\theta}{2}\right) + ew \geq \frac{Ve+2w}{2\theta}e\frac{V}{2} + \frac{Ve+2w}{2\theta}w - \frac{\theta}{2}\left(\frac{Ve+2w}{2\theta}\right)^2 - qP.$$

This yields that the minimum probability of auditing a project of type V to implement (e, e) as a Nash equilibrium is as follows:

$$q((e, e), V) = \frac{(e(\theta - \frac{V}{2}) - w)^2}{2\theta P}.$$

Finally, it can be easily noticed that $q((e, e), V)$ is a strictly increasing function in e and strictly decreasing in P and V , as we wanted to prove. ■

Proof of Proposition 5. If the regulator can perfectly distinguish the type of the project, it will solve the following maximization program:

$$\text{Max}_e \left\{ W((e, e), V) = 2 \left[\Pi((e, e), V) - (1 + \lambda)k \frac{(e(\theta - \frac{V}{2}) - w)^2}{2\theta P} \right] \right\}$$

subject to

$$(1) \frac{\sqrt{2\theta P} + w}{\theta - \frac{V}{2}} \geq e \geq \frac{w}{\theta - \frac{V}{2}}$$

$$(2) \frac{\theta}{\theta - V} \frac{2w}{2\theta - V} \geq e.$$

Constraint (1) implies that the audit probability $q((e, e), V)$ is well-defined, that is, it belongs to the interval $[0, 1]$. Expression (2) indicates that research firms should be better off under the social Nash equilibrium (e, e) than under the noncooperative Nash equilibrium without public intervention $(e^{nc}(V), e^{nc}(V))$.

From condition (1) it is straight forward to see that, for $P = 0$, the research effort for a type V project is just the noncooperative Nash equilibrium without intervention and the probability of auditing is equal to zero. If P is strictly positive but not high enough, condition (1) binds and the optimal research effort is $e = (\sqrt{2\theta P} + w)/(\theta - \frac{V}{2})$. At last, if P is strictly positive and sufficiently high, the optimal research effort is the interior solution of the first order condition of the social objective function, $e = e^{FOC}(V)$ where $e^{FOC}(V) \leq e^*(V)$ with equality if $k = 0$. In all cases the optimal research effort is strictly increasing in V so that $\bar{e} > e$.

We will prove that even though the Government is not able to distinguish the type of the project, no type of RJV participants have incentives to lie and pretend to be other type.

Firstly, we will show that it is not optimal for low type firms to untruthfully declare they are high value. On the one hand, if low value firms lie about their type, they will have to exert the efforts (\bar{e}, \bar{e}) and be audited with a probability $q((\bar{e}, \bar{e}), \bar{V})$. However, the minimum audit probability to implement (\bar{e}, \bar{e}) as a Nash equilibrium for a low type project is given by

$$q((\bar{e}, \bar{e}), \underline{V}) = \frac{(\bar{e}(\theta - \frac{V}{2}) - w)^2}{2\theta P} > q((\bar{e}, \bar{e}), \bar{V}) = \frac{(\bar{e}(\theta - \frac{\bar{V}}{2}) - w)^2}{2\theta P}.$$

Then, low value firms will have incentives to deviate and the resulting Nash equilibrium effort is the one without intervention, $(e^{nc}(\underline{V}), e^{nc}(\underline{V}))$. On the other hand, if low value firms truthfully reveal their type they exert the effort $(\underline{e}, \underline{e})$ and receive a payoff $\Pi((\underline{e}, \underline{e}), \underline{V})$. By definition these profits are higher than firms' profits without public intervention so low value researchers have no incentives to lie about their type.

Secondly, we will obtain the condition for which high innovators have incentives to reveal their true type and verify that this condition is satisfied by the optimal solution in the pure moral hazard case. In this case, the minimum probability to implement $(\underline{e}, \underline{e})$ as a noncooperative Nash equilibrium for the high value firms is:

$$q((\underline{e}, \underline{e}), \bar{V}) = \frac{(\underline{e}(\theta - \frac{\bar{V}}{2}) - w)^2}{2\theta P} < q((\underline{e}, \underline{e}), \underline{V}) = \frac{(\underline{e}(\theta - \frac{V}{2}) - w)^2}{2\theta P}.$$

Then, the research effort $(\underline{e}, \underline{e})$ is implementable as a Nash equilibrium for a high type project and for them to have incentives to tell the truth the following condition must be hold:

$$\bar{e}^2 \left(\frac{\bar{V}}{2} - \frac{\theta}{2} \right) + \bar{e}w \geq \underline{e}^2 \left(\frac{\bar{V}}{2} - \frac{\theta}{2} \right) + \underline{e}w.$$

Given that the low value firms never want to lie, the Government will implement a research effort for a high type firm $\bar{e} > \underline{e}$ so that the previous condition reduces to

$$\bar{e} + \underline{e} \leq 2e^*(\bar{V}),$$

which is obviously satisfied by the optimal solution in the pure moral hazard case. ■

Proof of Proposition 6. The proof is immediate. From Proposition 5 we know effort monitoring policy is unaffected by an additional adverse selection problem though Proposition 1 implies a loss of welfare in patent subsidies. If both policies were equivalent in the pure moral hazard case, it is obvious that effort monitoring socially dominates patent subsidies in the moral hazard and adverse selection case. ■

Proof of Proposition 7. We have just to verify that, if the Government can distinguish the type of the project, P is sufficiently high and effort monitoring and patent subsidies implement the same research effort, social benefit is higher for monitoring, that is patent subsidies imply a

higher social cost. For P high enough and λ sufficiently small, we have that for a type V project, the effort implemented by monitoring $e = e^{FOC}(V)$ is equal to the research effort implemented by subsidies $e(S, V)$ if $k = -4\theta^2 P \frac{\lambda}{(2\theta - V)(1 + \lambda)(2\theta\lambda - \lambda V - V)}$. Given these value for the inverse of the auditing process efficiency, we have that for λ sufficiently small:

$$W((e, e), V) = 2 \left[e^2 \frac{V}{2} + ew - \theta \frac{e^2}{2} - (1 + \lambda)kq((e, e), V) \right] > W(S, V).$$

This completes the proof. ■

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